

THE AUGUST SCIENTIFIC MONTHLY

Edited by

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NEW BOOKS OF SCIENTIFIC INTEREST

The Nature of the Chemical Bond. L. PAULING. Illustrated. xiv + 429 pp. \$4.50. Cornell.

The author discusses the problems of chemical binding and the structure of molecules and crystalline aggregates of atoms and molecules without the use of higher mathematics. The volume is based upon the George Fisher Baker Non-Resident lectureship in chemistry at Cornell University.

Photography by Infrared. W. CLARK. Illustrated. xi + 397 pp. \$5.00. Wiley.

The author attempts not only to deal with what is known of infrared photography, but also with its underlying principles and its applications. The book is intended for the guidance of artistic, commercial and scientific photographers.

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A text-book on the science of the earth for college students in which the authors have endeavored to present only the essential facts of physical geology. Throughout they direct the student's attention to unsolved problems.

An Introduction to Floral Mechanism. S. G. JONES. Illustrated. xi + 274 pp. \$4.00. Chemical Publishing.

An introduction to the study of the structure, development and functions of the flower for college students. An attempt has been made to consider the flower as a mechanism of inheritance in order to utilize the principles of plant breeding.

The Genetics of Garden Plants. M. B. CRANE and W. J. C. LAWRENCE. Illustrated. xxi + 287 pp. \$3.25. Macmillan.

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A discussion of the problems and accomplishments of civil engineering for the layman. The author describes excavation and embankment, the construction of railways, bridges, docks and harbors, the control of water and the reclamation of land.

Science in a Tavern. C. S. SLICHTER. ix + 186 pp. \$3.00. Wisconsin.

A professor at the University of Wisconsin presents ten lectures on the Royal Society, the Literary Club and certain scientists, on various aspects of research and education and on the philosophy and meaning of science.

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Combining the popular and the technical, this is the first biography of Jean Charcot, leader of two French Antarctic expeditions, a naval captain in the war and an explorer in Greenland who joined in the search for Amundsen.

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This book is divided into two parts: *Positive Eugenics*; which takes up Population and Eugenics, Etiology, Constructive Recommendations, Racial Theories in Relation to Eugenics, Rational Marriage; *Restrictive Eugenics*; The Feeble-Minded, Mental Disorders, Epilepsy, Restrictive Measures and General Conclusions.

The Kantian Philosophy of Space. C. B. GARNETT, JR. xi + 287 pp. \$3.50. Columbia.

This study traces the pre-Kantian thinking of the eighteenth century and leads through the ideas of Kant to problems of the present. It then discusses to what extent they anticipate present-day theories in philosophy and mathematical physics.

THE SCIENTIFIC MONTHLY

AUGUST, 1939

A NEUROLOGIST MAKES UP HIS MIND

By Dr. C. JUDSON HERRICK

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I

A SEPTUAGENARIAN having reached the age appropriately characterized as his anecdotage may be expected to have made up his mind about some things. He likes to ventilate these matured opinions and to support them with anecdotes selected from his experience. If these experiences include a life-long study of the brain, its evolution, development and normal functions, his interest may go beyond the particular opinions about which he has made up his mind to the larger questions, How does one make up his mind about anything? What kind of stuff is a mind made of and where does this mindstuff come from? This is our present theme, and incidental to it some beliefs will be expressed about minds in general and their relations to many other things that come within our experience.

At the outset I shall avail myself of the privileges of anecdotage, for this must be a personal record, based primarily upon what I find in my own mind. This mind is the only one that I know anything about at first hand. In this domain my own experience is the ultimate court of appeal.

I have made up my mind that this mind of mine is something that I myself have made. It has grown up with me. It is part of me as truly as is my body. It is not something added to my body to make it go. It is not something that I

have. It is something that I am. It is an active part of me, something that I am doing. There are no mental states, only mental acts. What the psychologists call the content of my mind is the pattern of this performance of mental work by bodily organs. Thinking is real work as you know very well if you ever tried it. It makes you tired, and it is your body that is tired because it is the body that is doing the work, as has been proved by the Benedicts with their calorimeter.

Our minds, then, are not given to us by kindly fairies or handed down to us ready-made in the genes or by tradition in social heredity. However we may be influenced by hereditary organization, by social pressure or mob-psychology, it remains true that every mind inheres in a single person; it is something that the individual has made and that he alone can use. It is this personal, this solipsistic, attribute of mind that makes us so jealous of it.

II

As a neurologist I am a naturalist, and what we are undertaking here is a scientific approach to our theme, an inquiry into the natural history of mind. We should, then, try to make clear what we are talking about, what we mean by mind.

There are as many definitions of mind as there are schools of psychology and

philosophy. Our minds bother us. Our most serious troubles are mental, and many problems of practical life and of science would be simplified if the mind were given a holiday. Many people do this more or less deliberately with results not always fortunate. Some objective psychologists have done their best to lay the ghost, but it will not down. It does not do any good to try to solve a difficult problem by ignoring the troublesome factors or by identifying mind with every sort of nervous action, with adaptation or with all totalizing or integrative functions. And panpsychism is a speculative excursion of more interest to metaphysics than to science.

For our present purpose the traditional usage is adequate: My mind is my awareness of what is going on. I shall not try to define this; I don't have to, because I experience it, and so do you; but I do have to accept it as a natural phenomenon, and as a naturalist I can, therefore, claim a legitimate scientific interest in it. The possibility of scientific treatment of the subjective has been denied, I know, but this denial is based on erroneous assumptions, that is, on the traditional doctrine that my mind is a ghost and not an organic part of me.

The aim of natural science is generalization and the method is a survey and comparison of particular things or events which have come within experience and abstraction from them of some general characteristics common to all of them. Science can do nothing with an isolated fact. How, then, can we investigate scientifically anything so intimately personal, so unique and detached, as the idea or the emotion that has just flashed through my mind?

This is the naturalist's dilemma, which is resolved very simply by the transcendentalists, who say there is no problem here because the mind belongs in a spiritual realm which is not bound by the rules of the natural order. This is the

tradition of the New England Protestant orthodoxy in which I was brought up and of such teaching of psychology and philosophy as was offered in my early schooling. But it does not square with my experience as a neurologist or in the common affairs of adjustment to things and people in the daily routine of life.

Common observation shows—if it shows anything at all about human nature and conduct—that my conscious motives, what I want, what I work for, and my ideas about it, are actually caused by previous events, some of which are conscious and some are unconscious, some inside my own body and some outside. All these are natural events, and no one of them is an isolated event. Even our most intimately private mental experiences have discoverable relationships with other things and events. They can, therefore, be investigated scientifically, for the study of relationships is the basic scientific method. All that we know about anything is its relationships; in fact, the thing is defined by these relationships. This holds for everything in our natural cosmos from electrons to faith, hope and charity.

If I make up my mind to sell my house and move my family to a hotel, this decision is the result of countless things that have happened before—changes in the physical and social environment, increase in taxes, the state of my health or perhaps the desire for ready cash to finance a speculation. The relation between these previous events, both the objective and the subjective, and my present motive is a true cause-and-effect sequence by all the rules of scientific evidence that we commonly apply in other fields of inquiry.

From the other angle my motive in advertising my house for sale, which is of course a conscious act, is also a real cause of some later events. If I find a purchaser and invest the proceeds in a wild-cat speculation, the loss of my fortune

affects all the rest of my life and the lives of my children. Here we have a mental or "spiritual" event actually having material consequences, and nobody would challenge it as a cause-and-effect sequence if it were not for a preconception or taboo rooted in mysticism and mythology.

It should not be necessary to labor the point that mind and body form an organic unity. We have no experience at all of any mentality apart from bodily organs. This is the opinion of the business executive when he pays a large salary to "a man with brains." Here is a case where the popular idea stands up under the most searching scientific criticism better than the sophistries and dogmas of the schoolmen. Yet even those of us who are biologically trained are apt to give only lip-service to this sound scientific conclusion. The tradition of the pre-scientific mythologies is so deeply implanted that we often fail to recognize its influence. Most people still cherish some modern version of those primitive demonolatrics which split the human personality up into physical and spiritual components.

But my mind is not something detached or detachable from my body and so capable of dallying at large independently of the rest of me. Whatever may be acceptable in theology and metaphysics, the biologist as biologist can not be a dualist, a trinitarian, a hydra or any of the other fabulous chimaeras of our mythologies. All nature as he knows it is an orderly unit, and anything outside of this integrated and law-abiding system of things and events is unnatural and therefore out of reach by the method of natural science. Our present interest is to see how far we can go in the exploration of the mental life without overstepping the boundaries of the natural order.

It is obvious that even in the field of medical practice the ghosts of traditional spiritism have not yet been exorcised. The average physician is apt to neglect

the mental attitudes of his patients, forgetting Osler's teaching that mental therapy—he called it "faith"—is the most potent remedy of his pharmacopœia. Even the surgeon should not neglect it. The late Dr. Billings, toward the end of his distinguished career as an internist, underwent a major surgical operation, after which he is reported to have said that every surgeon before being permitted to perform an operation should be required to submit to one himself. This, no doubt, is asking too much. Nothing so drastic has ever been tried, except perhaps by the psychoanalysts.

In psychiatry a methodological barrier has been set up between so-called "organic" and "functional" diseases. The treatments required in the two cases are indeed radically different. If a toxic goitre is diagnosed as a cause of mental disturbance, the surgeon may effect a cure. But our most distressing cases of mental disease are as yet known only symptomatically, that is, as mental disorder. Knowing nothing of the colligated bodily disorders, we apply mental therapy, often with gratifying results. Functional disorders may be treated by functional therapy; but where this fails, as alas! it does too often, we are thrown back upon a search for causes, and, as we have seen, the causal complex of any mental process is a web of structure-function relationships which must be seen in its entirety before we can hope for complete understanding. The exclusively mentalistic systems of some psychiatries are rooted in transcendental philosophy. They have, accordingly, an internal consistency and in some cases good practical results, for our mental life is normally orderly and some of the laws of this order are obvious within the domain of introspective experience alone. Yet this type of medical practice at its best has serious limitations which can not be wholly overcome by the most scrupulous care on the part of the psy-

chiatrist in referring his patients to other specialists for diagnosis and treatment of possible organic complications. For the psyche has no existence apart from the soma, and the psychiatrist, like every other physician, must treat his patient as a whole and not some disembodied complex of symptoms.

Do not misunderstand me. It is not recommended that mental therapy be abandoned and replaced by organic therapy. That would be a blunder far more serious than the neglect of organic therapy by a psychiatrist. Organic therapy and mental therapy must converge upon the patient. The practice of mental medicine must employ its own armamentarium of principles and technique which are as different from those of other specialties as surgery is from hydrotherapy. But the psychiatrist as truly as the surgeon must be first a physician and then a specialist. This is fortunately now fully appreciated by progressive psychiatrists, as typified, for instance, by Adolf Meyer's psychobiological approach to mental disease.

III

Having now decided that my mind, that is, my awareness, is a vital function, we come to the nub of the question—How is my mentality related with other vital processes, what is the apparatus employed in thinking, and how does it work?

There are two traditional formulations of this problem. First, How does a body make a mind? and, second, How does a mind make a body? These questions in one form or another have been debated for centuries, and we are no nearer the answer to-day than was Democritus or Plato. I am convinced that the question formulated in either of these ways, that is, in terms of either traditional materialism or traditional idealism, is insoluble.

Those dualistic philosophies which segregate the physical and the spiritual

in two parallel but independent and incommensurable realms of being are incompatible with any kind of natural science. And those traditional monistic systems which postulate either matter or mind as the primary or ultimate reality and the other as secondary or even illusory are equally sterile and misleading in the domain of natural science.

Things and their properties, mechanisms and what they do, organs and their functions, human bodies and human experience, can not be divorced in this way. What nature has joined together, let not man by artifice of logical or metaphysical analysis tear asunder. These things do not exist separately. To abstract one from the other is to annihilate both. Count Korzybski in his "Science and Sanity" has exposed the futility of these elementalistic systems. His definition of structure is dynamic, in terms of relations. Bodily structure, accordingly, is not one element, its function another, and its mental experience a third, for these can exist and be defined only in their relations one with another and with the surrounding world with which they are in adjustment.

Of course, we experience these things differently, for we do not live in a world of pure experience. We live relativistically, and our finite experience can not hope to encompass ultimate reality or any of the other absolutes of the metaphysicians. "For now we know in part, and we prophesy in part," and the human mind can not hope ever to attain "that which is perfect." Neither the Apostle Paul nor any other philosopher has ever succeeded in encompassing the infinite within the three-pint capacity of a human brain.

If now you demand specific and detailed answers to the questions, first, What are the bodily organs of the mental processes?, and second, Exactly how do these organs operate in the performance of mental work?, the neurologist can

supply a great deal of information about the first topic. The right answer to the second question is that we do not know. The knowledge already available about the bodily apparatus employed in mental processes and recent developments of new methods and instruments of precision encourage the hope that this second question is not insoluble.

It is possible to find out what parts of the body are actively engaged when we perceive a flash of light, when we are hungry or angry or when we imagine a muscular movement without actually executing it. We do not yet know all about any of these processes, but it is a great gain to have identified some of the organs involved and to be able to record quantitative measurements of some of their activities. We are beginning to know just where to look for other essential facts.

One general statement may now be made with complete assurance. The search for some particular localized organ of consciousness in general or of any particular conscious experience is as futile as was Descartes' identification of the pineal gland as the seat of the soul.

If at night I am looking at the sky, recognize one of the stars as our nearest neighbor, Alpha Centauri, and am steering a boat by the light of that celestial beacon, then the bodily organs involved in this mental act include eye and brain and muscle, all acting in reciprocal interplay. Indeed, the dynamic system operating is more far-reaching than this, for the star is also an essential component. It follows that the causal complex of which my conscious control of the course of the boat is one component embraces, not only an intricately linked series of very diversified bodily activities, but also events which took place 25 million million miles away and nearly five years ago, for Alpha Centauri is distant 4.35 light-years from the earth.

If we attempt to view this causal situa-

tion in its entirety, we recognize a number of things and events which are localized in space and time and which are locally segregated as organs with specific functions, such as sense organs, groups of cooperating muscles, reflex arcs, and so on. Each of these "partial patterns," as Coghill calls them, has a certain measure of unity and individuality. These local and partial patterns are woven together into larger "total patterns" which involve integrated activity of the organism as a whole or major parts of it.

Now, thinking is a total pattern. It is not performed by any linkage of particular nerve cells or centers in fixed and stable combination, like the arrangement postulated in the traditional diagrams of the reflex arcs. The search for localized cortical centers which perform the functions of perception, ideation, imagination or volition is vain. These, it is true, are acts performed by the body and specifically by the cerebral cortex in a restricted sense; but no one of these acts is ever exactly repeated, the set-up of conditions is never twice the same, and the cortical apparatus at each successive moment of the ceaseless ebb and flow of nervous impulses through its inconceivably complex web of nervous pathways is under the influence of outside events on both the sensory and the motor side. The sensory systems play upon the cortex at every moment of waking and sleeping life and all motor activities are reported back to the cortex and in turn influence subsequent cortical adjustments.

Our awareness of what is going on, the content of consciousness, is elaborated (we know not how) from these sensori-motor experiences. These may be recombined in new patterns in imagination, fantasy and abstraction, but even invention and creative artistic inspiration can not go far beyond the domain of sensory experience. The most inspired genius can conceive no glories that are other than kaleidoscopic recombinations of

what he already has sometime sensed. A scientific hypothesis is old facts reset and redirected, and the heaven of apocalyptic vision has gates of pearl, streets of gold and diadems of jewels of earthly form.

IV

Now we come back to the original question, What kinds of stuff are minds made out of? The answer seems to be that mindstuff is bodystuff. This does not mean that mind is matter or that matter is mind. Neither matter nor mind is inert structure. A structural psychology is to-day outmoded as completely as is the atomic physics of a generation ago. Matter is not something passively acted upon; it is a very lively thing and its activity is inherent in its structure. The biologist is driven to the conclusion that some special patterns of material structure exhibit the properties (that is, the activities) of life. This living substance we call protoplasm. Following the same line of evidence further, the conclusion is equally unavoidable that some special structural arrangements of protoplasm exhibit the properties of mind, that is, an awareness of some components of the flowing network of process which is characteristic of this particular kind of structure.

Life is still a mystery. We have not yet found a scientific formula for it. Mind is still more mysterious. But the preceding statements seem to rest on the safe ground of well-validated scientific evidence. The mystery of mind will probably remain, for if mind is a manifestation of the activity of structure, the mind can not know itself as awareness and at the same time have *direct* knowledge of the structural apparatus that performs the function of knowing.

This seems to be an inherent limitation of our nature as finite beings. Our awareness is a process patterned in the four dimensions of space-time. The apparently static structural patterns of naive experience seem like objectified

cross-sections of the process, pictured as arrested motion like a single frame of a moving picture film. The temporal dimension is eliminated. But temporal relations are essential features of mentality. There are no mental states, only mental acts.

All our knowledge of structure is indirect, and must be so. From this it does not follow that material structure is illusion or less real than mind. The naturalist must be a practical realist—and so must everybody else, for if we do not adjust our conduct to the realities of the objective world we quickly perish.

Just as we have learned to use subjective experience as a token or representation of things and events of the outer world to which we must adjust and also of the operation of certain bodily mechanisms (as yet very imperfectly understood), so conversely we may use the behavior and bodily structure of other men and animal kind as objective tokens or indicators of what they are probably experiencing. This indirect evidence about other minds than my own is more reliable the closer the resemblance between these other patterns of behavior and bodily organization and those which I myself exhibit. I feel, for instance, that I understand my wife's mind better than I do that of my dog and I am sure that my understanding of both of them leaves much to be desired.

Since the organ and its function are inseparable, once we have discovered this relationship we can safely infer the presence of the organ if the function is manifested and the presence of the function wherever the organ is found. A competent zoologist can tell a great deal about the habits even of an extinct dinosaur from a study of its skeleton. We use in this way not only bodily structure, but evidences of animal handicraft, beehives, beaver dams, and the like. So also the archeologist may reconstruct and evaluate an extinct human culture, corre-

lating utensils, works of art and dwellings with skeletal remains, cranial capacity and cephalic index.

Because this indirect evidence is all that we have, we must make the most of it. This method is serviceable in proportion as our knowledge of both structure and function is complete and reliable. So we study comparative anatomy, comparative physiology and the comparative embryology of both structure and behavior. But the most comprehensive knowledge of these things will never take us to the desired goal unless all the facts are actually brought together and converged upon the particular individual whose vital processes are under investigation.

For an adequate understanding of the actual relationship between bodily structure and performance it is necessary to know the past life of the individual, both his personal development and his ancestral or evolutionary history. We look for sources, for beginnings, and then follow the steps of subsequent development and differentiation. By way of illustration let us now summarize briefly two programs of research into the origin and early development of behavioral capacity of the individual.

We owe to the insight, skill and indefatigable industry of Coghill the demonstration of the importance and the practicability of this correlation of development of patterns of behavior with the organs which actually execute the behavior. He selected for intensive study a primitive and generalized animal where the essentials of the problem are reduced to simplest terms, the salamander, *Amblystoma*. This was a fortunate choice, for during the span of the forty years of his labor this animal has proved to be the most serviceable type for a wide range of researches upon fundamental biological problems.

Dr. Coghill's first step was the determination upon statistically adequate num-

bers of specimens of the actual sequence of development of patterns of overt behavior which are characteristic of this species. He then took a series of specimens, each of which was known by test to have reached a specific stage in this physiological scale, and subjected every one of them to detailed microscopical study, thus revealing the corresponding series of structural changes. It has been my recent good fortune to repeat many of Coghill's observations on a different series of specimens prepared by methods different from his, with full confirmation of his findings. These studies have stimulated many others, so that we now have comparable observations upon a wide range of animal species.

It is already clear that the sequence of events in the process of maturation of the action system may be very different in the various kinds of animals. *Amblystoma*, which may hatch from the egg before the twentieth day and thereafter swims actively, shows from the start a different pattern from that of the toadfish, whose yolk-laden eggs develop more slowly. It is unsafe to carry over generalizations from one species of animal to another without actual control by critical observation and experiment. As the late W. K. Brooks used to say, "The only way to know is to find out."

Some men have been described as rats, but no rats are men. The course of human prenatal development does not run exactly parallel with that of any of the other animals whose fetal behavior is now under investigation. Yet the difficulties in the way of successful prosecution of studies of human prenatal behavior are very numerous and baffling. Fortunately several investigators have to varying degrees overcome these obstacles. The pioneer was Minkowski. The most completely documented and systematic observations are those of Hooker. Parallel with the accumulation of these records of behavior, anatomical studies of the ac-

companying changes in structural development are in process. These researches yield a wealth of facts which can now replace speculation about many features of early human development which are of fundamental value in fields as diverse as embryology, physiology, anthropology, psychology and medical practice.

These studies of embryological origins and subsequent differentiation do not go back to the beginning, for every individual is endowed by his ancestors with a characteristic hereditary organization. This is his working capital as he begins his career as a separate person. These inherited potentialities and limitations must be known and carefully invoiced and appraised. Neither nature nor the natural man can make something out of nothing or perform any other miracle. It follows that the entire evolutionary history of the race must be surveyed to learn as much as possible about the genetic composition of the fertilized egg, for this tiny fleck of protoplasm has somehow concealed within it all the potencies which are transmitted to the germ from countless generations.

My own attack upon the problem of the sources and growth of the apparatus of our mental capacities is directed toward a search for evolutionary origins. Trained as a comparative anatomist and structurally minded, as an anatomist must be, I fortunately was taught when very young that structure has no meaning apart from what it does. There is general agreement that the human cerebral cortex is the master tissue in the control of our conduct. It is equally clear that this cortex has been elaborated in the course of many million years of intense evolutionary struggle for survival from a simpler and more primitive sort of nervous tissue which is not cortex as we define it. It may help us to understand the still unsolved mysteries of cortical activity to inquire where the cortex came from. Fishes have no cortex, though the

rest of the brain is organized on much the same plan as our own. Can we trace the emergence of cortex from primordial tissue which is not cortex, and can we discover the agencies operative in effecting this transformation?

Our knowledge of the texture of the brains of fishes and of representatives of all groups of animals from fish to man is very extensive. We know the fossils of these various types of animals from early Silurian times until now, and from their skull casts we can restore the forms of their nervous systems and write a fairly accurate history of the evolution of the brain.

From the assemblage of all available evidence it is obvious that when some primitive ganoid fishes developed lungs and were able to emerge from the water as air-breathers these revolutionary changes in the mode of life were reflected in the structure of the nervous system. This transition from primitive amphibian fishes to true amphibians was effected perhaps three hundred million years ago, and fortunately we still have with us living representatives of some of these transitional forms. These are the critical species for investigation of early stages in the emergence of cerebral cortex from its primordial matrix in the cerebral hemispheres. I have, accordingly, for now nearly fifty years devoted myself to the study of the minute structure of these amphibian brains, with especial attention to *Amblystoma*, the same salamander which Coghill employed in his classical researches.

Even a brief summary of these investigations and similar studies by other comparative neurologists would require a thick volume of very technical neurological description. It is possible to recognize in fishes and salamanders and frogs, which have no cortex, the parts of the forebrain within which cortex emerges in reptiles and to discern some of the physiological agencies there opera-

tive which prepare the field for cortical differentiation.

In the more primitive amphibian species most of the activities are generalized mass-movements. Their brains, accordingly, possess few sharply localized reflex arcs, but the entire nervous fabric is woven together by an intricate feltwork of very fine and widely branched nerve fibers. This tissue we call neuropil. It seems to be the chief apparatus of integration of behavior and of those totalizing activities which the gestalt psychologists have brought to light and which can not be fitted into the stimulus-response formula. It is also probable that it is employed in conditioning of reflexes—a learning process—and many other forms of modifiable behavior. This neuropil, together with its derivatives in higher brains, such as the reticular formation, is the parent tissue from which all the more highly elaborated organs of integration and totalizing functions have been differentiated. This non-specific and labile tissue and many complex cerebral organs derived from it may be regarded as an equilibrated dynamic system which operates more or less as a whole and in constantly fluctuating patterns depending on the sensori-motor activities at the moment in process in the more sharply localized tracts and centers of the analytic systems. The further differentiation of this tissue culminates in the emergence of cerebral cortex within particular fields of the cerebral hemispheres, and the early chapters of the history of this critical period in the evolution of brains can now be written.

We can also trace the progressive complication of the texture of the cortex in the series of animals from serpents to men and so arrive at some conclusions as to the difference between the wisdom of the serpent and the wisdom of man. For, as Dr. Cannon has graphically shown, there is a wisdom of the body and, as I maintain, there is no other kind of wisdom.

V

The human brain is the most complicated structural apparatus known to science. If all the equipment of the telegraph, telephone and radio of the North American Continent could be squeezed into a half-gallon cup, it would be less intricate than the three pints of brains that fill your skull and mine. More than half of this brain tissue is cerebral cortex and parts immediately dependent upon it. The most ungifted normal man has twice as much of this master tissue as the most highly educated chimpanzee.

This cortex is a sheet of grayish jelly spread over the convolutions of the cerebral hemispheres within which are embedded ten thousand million nerve cells. It is a conservative estimate that each of these cells is in anatomical and (potential) physiological relation with at least a hundred other cells by means of an interwoven fabric of nerve fibers of inconceivable complexity. The possibilities of functional patterns of interconnection among these nervous elements are practically infinite. These arrangements are not haphazard; they are orderly; and it is the neurologist's task to discover the laws of this order.

Good progress in this program is already recorded, and the immediate future offers promise of still more rapid advance, for we have new points of view and new instruments of precision. I have ventured the prediction that the recently developed electrical methods of recording nervous impulses by means of the oscillograph and radio tube amplifiers will enlarge the field of nervous physiology as fruitfully as the science of anatomy was revolutionized by the invention of the compound microscope.

Examination of the brains of animals from low to high in the scale and of mankind from early fetal stages to the adult reveals differences in texture which are directly correlated with patterns of behavior and presumptively with types of

experience. This presumption can be tested in the case of the human brain, where correlated studies in clinical neurology and neuro-pathology reveal numberless clear demonstrations of the relations between particular cerebral organs and various sorts of conscious experience.

It is possible to trace, in the course of vertebrate evolution and in human embryological development the progressive maturation and complication of cerebral tissue, first in the older stem portion of the brain and later in the cortical fields, and to correlate these changes with the gradual transfer of control of behavior from brain-stem to cortex. The more stereotyped reflex and instinctive types of behavior have their central adjusters in the primitive brain-stem. The maturation and elaboration of the cortex comes later, and with it greater capacity for learning by personal experience and all the higher mental process which make this possible. These two kinds of control of behavior—that is, the relatively stereotyped innate reflex and instinctive as contrasted with the more plastic individually learned—have a common origin in the adaptability of all living substance. They are not sharply separated, and every human activity is a blend of both of them. Yet the distinction between them is of great practical significance, and increasingly so as we pass from lower to higher species of animals. The nervous apparatus employed in the primitive subcortical types of adjustment is recognizably different from that of the cortical adjusters and the enlargement of our knowledge of these differences is now at the focus of interest, for this is the key-problem of physiological psychology.

VI

In my own experience the feature which seems most characteristic of the higher mental processes is the ability to use mental symbols of one sort or another

as tools of thought. These symbols evidently have grown up by abstraction from many particulars of something which is common to all of them; thus all squares differ from all circles in easily definable ways, and for these differences the words are symbols. Language is, of course, the chief vehicle of these symbols, but it is not the only one.

The symbolisms of language, mathematics, pictorial art, and so forth are consciously employed. Ability to use abstractions of this sort has grown up very gradually in the life of the individual and the history of the race. In its more primitive forms it may be, so far as we know, entirely unconscious. All plants and all animals show some capacity to adjust their behavior to the uniformities of their natural surroundings. In racial experience these common features have been abstracted from the heterogeneous environment and by natural selection or other biological agencies woven into the hereditary texture of their bodies so that they make these adaptive adjustments to the alternations of day and night, change of seasons, and so on quite "naturally." Here we see on the most elementary biological plane an abstraction from mixed experience of some general features which enable the animal to adjust himself in advance to future events before they happen, as when the fur thickens in preparation for winter and a bee, wasp or beaver lays by his store of food in a skilfully constructed dwelling.

This "animal faith," as Santayana calls it, may be exercised blindly and unwittingly, but it seems to be the germ from which all higher types of abstraction and symbolism have grown. When a rat is taught to discriminate between a square and a triangle, regardless of size, illumination or arrangement of the test objects, we are dealing with a higher grade of abstraction which must be individually learned, for this ability is not

part of the rat's hereditary endowment. If this sort of learning has any intelligent control, it is of rather low order, though even in rats Dr. Norman R. F. Maier, of the University of Michigan, has objective experimental evidence of types of performance which fundamentally are indistinguishable from human rational behavior.

The progressive enlargement of this capacity for abstraction can be tested in terms of objective behavior. Experiments with monkeys by Kluever and Bucy are now in process which show that destruction of certain definite cortical structures may cause a mental disorder (agnosia, asymbolia) comparable with the simpler types of human aphasia. The acquisition of symbols for abstractions provides a useful objective index of the growth of intelligence, whether the symbol is expressed as gesture or a spoken word.

Parallel with these studies of the development of patterns of behavior and comparative psychology, we have a series of anatomical descriptions which show a close correlation between the grade of performance which an animal (or a child) can exhibit and the structural differentiation of the nervous system. These details are intricate and technical, but I wish to make it clear that we are not merely guessing when we say that it is possible to cite a wealth of facts about the location, structure and physiological properties of the bodily organs employed in making mental symbols and in all those higher rational processes which employ them—in short, the semantic functions.

I have elsewhere suggested a biological classification of the kinds or grades of learning under three heads: First, organismic or protoplasmic learning, that modifiability by use or practice which is a general characteristic of all living substance, for all protoplasm can learn. Second, sensori-motor or neural learning,

whose exercise requires a differentiated nervous system. This is typified by a rat's ability to learn to make an errorless run through a maze. Third, semantic or cortical learning which works with ideas and mental symbols of various grades of abstraction. This kind of learning can not go far without the aid of language and is a token of our humanity. It is distinctly a cortical function.

The transfer in higher mammals of the dominant control of conduct and of the course of conscious experience from brain-stem to cortex and from physiological to psychological technique has momentous consequences. The mental symbols elaborated in some unknown way by the integrative apparatus of the human cortex give to mankind new tools of adjustment which have extended the reach of his control from the present into the future. The human brain, as Sherrington aptly expresses it, is "fraught with a germ of futurity."

Mental symbols and their objective signs in language, mathematics and so forth are the indispensable tools of the life of reason. With the help of these tools mankind can preserve and profit by the past experience of the race as recorded in tradition and literature and by imagination and invention enlarge his understanding and control of the inorganic, organic and human agencies of production and enjoyment. And of far more importance, he can predict the future and lay out his present course of action in the light of probable future consequences of the present act. The most intelligent brute lives mainly in the present. Men attentively bind the past and the future into their present and thereby become as gods, knowing good and evil.

This capacity for "time-binding," as Count Korzybski phrases it, is perhaps our most distinctive human characteristic. The ability to select from among several possible courses of action the one which intelligent foresight indicates will

at some future time yield the satisfaction desired provides the key which opens doors of opportunity which are closed to all the brute creation. We are free to make choices in the light of past experience and to make up our minds about what we propose to do about it in rational judgment. This free voluntary choice sets the musty problem of the freedom of the will in a natural frame unobscured by any fog of mysticism, because this life of reason is part of our natural lives as sentient beings.

It is this which makes it possible for every individual to lay out an intelligently planned program of self-culture which shapes the course of his own growth in competence and the achievement of higher satisfactions. It is part of our apparatus of regulatory control, and it carries with it a personal responsibility for character building and for all the conduct manifested by the characters which we have built. Our natural freedom involves an equally natural responsibility. And this becomes, by definition, a moral responsibility as soon as a social component enters into the intelligent analysis of situations requiring the exercise of voluntary choice.

That is what our brains are good for,

and the salvage of our civilization from its present peril of reversal to barbarism depends on our capacity by educational and other means to cultivate in all our people a more intelligent appraisal of the values sought and ability to curb irrational passion and selfish greed for wealth or power in the interest of those social values which make civilization possible. At the present stage of human culture a stable social organization is absolutely essential to personal welfare. This implies a proper balance between personal profit and the public good, and this is what we mean by moral conduct. We have, in fact, reached a stage of cultural evolution where some of the moral values have actual survival value. Without them our civilization perishes and we perish with it.

It follows that a natural system of practical morals can be elaborated from this simple principle: That social stability upon which the survival and comfort of the individual depend and that moral satisfaction upon which his equanimity, poise and stability of character depend arise from the maintenance of right relations with our fellow men. The right relations are those which are mutually advantageous.

CUTTHROAT COMPETITION IN THE SEA¹

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LEST the terminology lack significance to others, let me explain the wording of my title. Perhaps it has been two, three or more decades since I first heard the phrase "cutthroat competition" applied to the life and death struggle between and among many kinds of business enterprises. Whatever, however and whenever the occasion of its use that first attracted my attention, it made a strong impression upon me. Since then it has always carried the idea of desperate, heartless and insatiable strife for place and the means to sustain it. As my acquaintance with life and nature "in the raw" has expanded and progressed this idea has been transferred with slight modification to the relationships of lower organisms. Although we may not be able to say properly that they are vicious and heartless in their struggles for place and maintenance, it is surely correct to say that they, no less than man, are desperate and insatiable in their competitions with each other.

Ordinarily, so far as our acquaintance with human competition goes, we are disposed to think that Tom Jones, the plumber, has no competition with Bob Tate, the grocer, and that Richard Roe, the doctor, has no competition with John Doe, the lawyer. We are more familiar with conditions under which grocers are against grocers, doctors against doctors, lawyers against lawyers, and plumbers against plumbers. This is especially true when the means of maintenance are limited in any of these fields or others like them. But, as a matter of fact, any or all of those just mentioned may come into competition in seeking homes or favorable

sites for business. So it is in the sea. When certain conditions exist an organism may find competition only with those of its own kind seeking place and sustenance. But, certain other conditions may remove competition between kin while introducing competitions with widely different creatures.

Numerous aspects of competition of marine organisms might be mentioned, a few of which are selected for present discussion. To me, cutthroat competition appears to be more evident and more impressive among sedentary animals and plants, those living attached to solid objects as distinguished from those afloat (plankton) or those swimming (nekton) in or through the water. But discussion of their vicissitudes of existence may be clearer after references to the floatant (planktonic) and natant (nektonic) forms.

In Southern California seas many different kinds of animals, including man, prey upon the sardines. Under the stress of competition when sardines are relatively few it is probable that other animals would take the same attitude as man if they were able to establish or exhibit attitudes. They might accuse him and each other of reducing the supply, just as he accuses sea lions, sharks and birds. If given opportunity, all would attempt to get rid of competition by destroying the accused competitor. Lacking the ability to establish that attitude, the enemies of the sardine frequently make up for it by engaging in a race to kill which has some of the typical features of cutthroat competition, especially viciousness and heedlessness. When one sees a school of sardines being decimated or destroyed by ravenous barracuda, mackerel, bonita and

¹ Contributions from the Scripps Institution of Oceanography. New Series No. 58.

sharks, in the water, aided by swooping pelicans, terns and cormorants from the air above, he wonders that any small fish should be able to survive.

But, although less abundant than formerly, sardines do survive. On most days when the sea is smooth in clear weather half a dozen or more small schools may be seen from the laboratory windows of the Scripps Institution of Oceanography as they ripple the surface of La Jolla Bay. In one way it seems probable that competition of their enemies in destroying them has favored prosperity of sardine survivals by diminishing their own competition for food. One does not think of the sardine as a ferocious animal, yet it seems to be reasonably clear that if sardine numbers increased excessively their food supply would be consumed and diminished to the point where desperation of competition for sustenance among them would be as severe as that among the enemies engaged in their destruction.

The food of sardines consists of a number of different kinds of plankton animals and plants, all small and many microscopic. In Southern California seas the tiny crustaceans called copepods contribute largely to the food supply of these fishes. Some copepods are predatory, but most of those under notice here are plant feeders, living on diatoms, dinoflagellates and other microscopic plants. Inasmuch as they pick up this food material while swimming feebly through the water, there is not much opportunity for individual conflict over particular items. Like larger herbivorous animals, they browse along without much attention to each other. Even when food is scarce, it is difficult to see how they can oppose each other forcefully while getting it. Rather, we must suppose that the stress of competition between individuals appears only in seeking and grasping food particles over a wider range than usual, thus menacing the supply for others without direct conflict. But, of course, this kind of

competition may be as desperate and interminable as any.

Nor do the microscopic plants which constitute the phytoplankton escape competition. Through most of the year, in most seas, they are likely to be few in numbers and irregular in locality occurrence or distribution. One drop of water may contain a few to several individuals, while neighboring drops in that locality have none. In another locality few drops of water contain any. Investigators suggest that in one case light is not favorable, in another case that phosphates are deficient in quantity, in another case that temperature is not favorable, in another case that overgrazing by animals has made or kept the plant populations small, and so on. Whatever the unfavorable influence or lack of influence or the unfavorable combination of influences may be the condition almost always marks a period in which competition is negligible, the organisms present being spaced too far apart from each other to make any essential difference in the use of materials obtainable.

But, now and then, there are periods of days or weeks in which a combination of influences favors rapid growth, development and multiplication of microscopic plants of many kinds or of some particular kind. Toward the end of such periods the abundance of one or more kinds may increase until the sea water is discolored and looks "soupy."² 3. 4. 5 At such times one or more hundreds of individual specimens may be present in each drop of sea water over an area of several or many square miles through depths from the surface to one hundred feet or more. While there is still a great lack of information concerning the func-

² W. E. Allen, *Quart. Rev. Biol.*, 9: 161-180, 1934.

³ H. B. Bigelow, *Bull. U. S. Bur. Fisheries*, 40: part 2, 1926.

⁴ E. Haeckel, "Planktonstudien." Jena, 1890.

⁵ H. N. Moseley, "Notes by a Naturalist on the *Challenger*," London, 1879.

tional activities and physiological conditions of such dense populations it is well known that supplies of phosphates, nitrates and other nutrient materials are diminished in the area occupied. Therefore, it is reasonable to suppose that life and death competition for sustentative materials exists, even though it lacks any suggestion of strife of one individual against another.

So far I have noticed only those organisms which generation after generation spend their lives suspended (floating or swimming) in sea water. In addition to such as these there are vast multitudes of different kinds of animals and plants which spend only parts of their lives or cycles of existence in the same way. Populations as dense as any mentioned above are very common for short periods in certain tide pools, where sex cells, larvae and other floating or swimming forms are released in clouds by fixed (sedentary) organisms at favorable times. The water over almost any beach is likely to be clouded temporarily with reproductive materials and products or with propagating units at appropriate seasons of the year. Inshore waters in general may contain large numbers of plant and animal units of one kind or another at any time of year in warmer seas, some detached by surf or wave action, others normally detached forms of propagative or reproductive character. Sometimes these transitory populations take residence in coastal water masses at a time when they are occupied already by vast numbers of permanent residents. In such cases, competition of all kinds may reach critical intensity in the locality, some organisms competing for such operating essentials as oxygen to breathe, others competing for foodstuffs, still others competing for light, and all competing for space to be occupied by their bodies. In such populations one kind of competition will be found much more prominent than it ever becomes in populations of offshore waters; it is competition for reproduction.

Throughout most of the year any kind of a population in offshore waters is mainly active in growth and development. Even when a reproductive period involves a dense population, *e.g.*, one of sardines or copepods, it is not probable that reproductive competition is very great, the eggs and sperm being scattered in the water so rapidly that relatively few sex cells meet excessive numbers of the opposite type. Inshore, the condition is likely to be different, each egg liberated in a tide pool being surrounded by enormous numbers of sperms competing for union, or each female organism being besieged by great numbers of struggling males.

Among the larval or juvenile forms of sedentary organisms found in coastal waters another kind of competition of utmost urgency appears as individuals get ready to attach themselves for the stationary phase of existence. In most localities unoccupied surfaces with satisfying characteristics for young home-seekers are relatively rare. Not only are appropriate submerged surfaces or surfaces frequently submerged already occupied by animals and plants of a preceding generation, but many surfaces which lack full fitness for occupancy are also in use. Therefore, in trying to find a lodging place the new settler is confronted with opposition (passive or active) from old settlers of many kinds in addition to rivalry of those of its own generation.

Under these circumstances the outlook for youngsters of most kinds seems very dark, even hopeless. And, one might suppose that the competition for space would be extremely one-sided, nearly all the fatalities being among those who seek rather than among those who possess. However, no data have ever been compiled which are adequate to support an absolute generalization to this effect. No matter, the finding of acceptable lodgment by a successful seeker does not solve or terminate the problem of space rela-

tionships. Except, perhaps, for certain unicellular forms the act of process of attachment and settlement is merely the beginning of a period of growth and expansion in which the need for more and more space is just as urgent as ever until the end of that phase of existence is reached. Many different kinds of sedentary animals and plants live under perpetual continuance of this stress of strife for place, barnacles, oysters, mussels, bryozoa, tunicates, hydroids, serpulids and a number of different kinds of "sea weeds" being especially prominent in numerous localities in Southern California waters.

Of these, the "California striped barnacle" (*Balanus tintinnabulum Californicus*) is especially favorable for attention, partly because of its great abundance and partly because of its rigidity of shell structure and the protuberant habit of growth. Years ago, Visscher⁶ found that barnacle larvae ready for attachment under experimental conditions were inclined to be meticulous, trying out one and another and still other spots on the surfaces offered for their attachment. It is difficult to believe that they would always behave this way in their natural habitat with myriads of their kind trying to find points for fixation at one time. Surely the need for haste would be so great that fastidious testing would be impossible, at least at the period of greatest abundance when the number attaching may be as high as three hundred per square inch.⁷ Certainly, several of the points selected by individuals in Fig. 1 seem to have been chosen without much attention to fitness, either because of the race for position or because of the diminishing range of choices as all spaces were filled. However, the fact that some of the surfaces of shells of the larger individuals lack occupants may mean they

had been tested and rejected for cause, although they may look to us much more favorable than the case of shell upon shell upon a shell attached to a fourth shown in Fig. 2. Still, there is plenty of evidence that preferences exist, not only for certain materials but for certain positions on solid objects.^{8, 9, 10}

The small insulated wire upon which this dense colony (Fig. 1) of small barnacles found lodgings was used to hold in place some submerged experimental plates at the pier of the Scripps Institution of Oceanography. It received no definite attention until after the colony had become conspicuous. Therefore, the history of the attachment activities is unknown. However, there was evidence to indicate that the surfaces of insulated parts were occupied much more quickly than the bare copper (if the latter was occupied at all, a matter difficult to determine positively because of the smallness of the bare area and because of overlapping or bridging of shells from insulation material). At any rate, crowding was more conspicuous and growth was far greater on the insulation material than on or over the copper. Evidently, the homeseeking larvae found the insulation surface so attractive that they tried to reach it again and again.

Directly or indirectly (shells on shells) more than one hundred larvae found attachment on the four-inch section of this wire (Fig. 1). It is impossible to guess the total number because many which had found lodgment at one time must have been destroyed without trace, leaving evidences only of the number mentioned. Of these, about twenty reached a shell diameter near one third of an inch, most of them being attached directly to the wire. It may be supposed that these had found lodgings on the wire soon after submergence, four weeks before its removal.

⁶ J. Paul Visscher, *Bull. U. S. Bur. Fisheries*, 43: Part 2, 1928.

⁷ W. R. Coe, *Bull. Scripps Inst. Oceanog., Tech. Ser.*, 3: 37-86, 1932.

⁸ J. Paul Visscher, *loc. cit.*

⁹ W. R. Coe, *loc. cit.*

¹⁰ W. R. Coe and W. E. Allen, *Bull. Scripps Inst. Oceanog., Tech. Ser.*, 4: 101-136, 1937.

But, a few were attached to shells of first settlers, which they resembled in size, doubtless because their superior positions not only enabled them to feed and breathe better but also because they reduced the supplies for the older animal. However, the first comer may have destroyed several of his fellows by expansion of his shell from pin-point size to bean size. Certainly, if several of the larvae of the first brood settled within one ninth of a square inch of the newly submerged surface all but himself were destroyed by the survivor, who may have been favored by first attachment and oldest growth, by ability to build shell most rapidly, by ability to build most resistant shell, by superior success in getting food or by other conditions and circumstances. Whatever the points in its favor may have been, the fortunate one was able to destroy rival residents on the space occupied by it at the time of observation. Coe¹¹ says that "only three or four barnacles can reach sexual maturity on any square inch of surface" and "with 200 to 300 young per square inch, even if regularly spaced, the mortality due to overcrowding must approximate 98 to 99 per cent." Competition for fixation space, therefore, appears to justify fully the application of the term "cutthroat competition."

But, competition between barnacle kin is not restricted to strife for place and space. Setting of one barnacle shell upon another has been mentioned in the preceding paragraph along with a suggestion as to interference with feeding and breathing. This suggestion deserves a little more attention. Suffocation and starvation may be caused in at least two or three different ways. Doubtless this fate is forced upon neighbors most frequently in newly formed colonies by individuals so fortunate as to get a lead in growth and development. Standing a little farther out from the surface than others, they get a choice of every kind

of needed substance available in the water, and this in turn enables them to grow out farther. Some even overlap less fortunate individuals or join a large neighbor in bridging them over. Perhaps less frequent is the condition in which one or more newcomers attach themselves near to the peak of the resident shell of a large specimen or even on its outer margin, sharing in the materials collected by

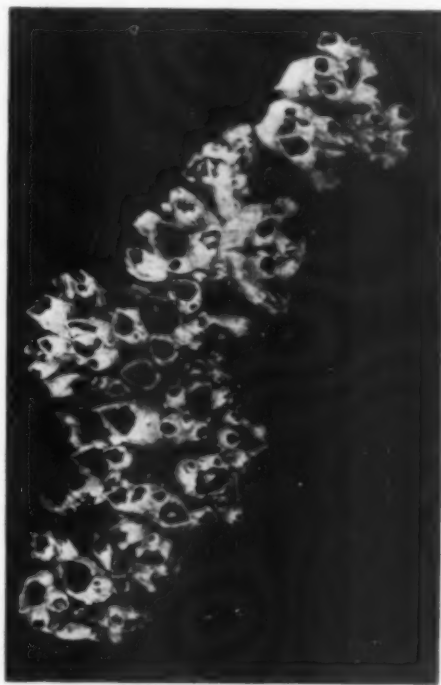


FIG. 1. CROWDED BARNACLES ON FOUR INCHES OF INSULATED WIRE, EIGHTH-INCH DIAMETER. SOME GAPS DUE TO SHELLS BEING DISLODGED SINCE DRYING BEGAN.

the occupant's activities until themselves large enough and strong enough to take nearly all as they extend their own shells across the mouth of the old one.

It should not be supposed that competition among barnacle kin is always, or often, so evident or so prominent as might appear from foregoing illustrations. It just happened that this wire was exposed at a time especially favorable for showing barnacle activities without much

¹¹ *Loc. cit.*



FIG 2. SUPPORTING SHELLS.
NEXT TO LAST SHELL TO RIGHT ON WIRE SUPPORTS
SERIES OF FOUR SIZES, THE SMALLEST SHELL
LOOKING LIKE A PIN-HEAD EXCRESCENCE AT EX-
TREME LEFT AT TOP.

evidence of other kinds of growth. Under ordinary natural conditions it is probable that rivalry of barnacle against barnacle might escape notice because of the prominence of competition of other kinds of organisms. Even in the wire dwelling colony there was a considerable beginning of encroachment of other living things, the most prominent being worms of two kinds, one a serpulid building white, calcareous tubes on surfaces of the barnacle shells, the other a dweller in sand-walled tubes fitted into angles and crevices around the bases of barnacle shells. The latter kind usually offers little threat to barnacle prosperity, but the former always carries the possibility of serious interference with welfare of individual barnacles or even small colonies. For one thing, these worms use some of the same

kinds of materials needed by barnacles, but principally they endanger the latter by their capacity for multiplying so rapidly at times that they may cover barnacle shell openings more or less and cause suffocation or starvation of the occupants.

In nine years of continuous observation of sedentary ("fouling") organisms in La Jolla Bay, Coe and Allen¹² found serpulids conspicuous in only one. Ordinarily they might show large abundance at times, but not in a way to suggest intense competition among themselves or very great interference with lives of other creatures. In August, 1935, *Eupomatus gracilis* appeared in such abundance on experimental equipment at the pier that they not only crowded out many other things but overlapped their tubes to such depths that many individuals in lower strata must have been killed. At about the same time they appeared in enormous numbers in San Diego Bay, choking with their tubes the condensers on certain vessels of the U. S. Navy (Coe and Allen¹³). This record of high abundance of *Eupomatus* is interesting and important because it illustrates the fact that populations not usually significant (at least in appearance) may become so at some time or other, either because of biological periodicity or because of fortuitous combinations of conditions favorable to their multiplication and development. From consideration of phenomena of this kind it seems necessary to conclude that any living thing may become highly competitive against its own kind, or other kinds, whenever the right combinations occur, no matter how peaceable, insignificant and innocuous it may appear to be in ordinary routines of existence.

One of the small crustaceans observed in La Jolla and San Diego Bays offers a still more striking example of this phenomenon, inasmuch as it had been not even noticed on the experimental equipment until 1933, although recorded from

¹² Loc. cit.

¹³ Loc. cit.

detailed examinations. This little animal was the amphipod, *Erichthonius brazilensis*, which occurred then in dense colonies living in mud tubes several layers deep. As observed before that time, the few specimens living in single tubes or scattered groups of a few tubes twined about the bases of algal, hydroidal and other small growths seemed entirely negligible in relation to the general welfare of the fixed populations. In 1933 they were noticed first in a colony having the form of a small island of mud in the middle of the surface of a glass plate 8 x 9 inches square. This mass stood out about a half inch from the plate, and it was riddled with the openings of the tubes, the walls not being readily distinguishable. Except for their short legs and lack of wings these animals were about as large as a mosquito. They were very lively, and they could move back and forth through the tubes with considerable speed. Therefore, it is not likely that those inhabiting the deeper tubes were seriously hampered by those in the outer ones. This seems the more probable because enormous colonies observed in San Diego Bay on the flat bottom of a barge inhabited a mass of mud more than twice

as thick, and those in lower layers seemed to be just as vigorous as those in outer layers. 1933 was their "big year" in La Jolla Bay (Coe and Allen¹⁴) their volume on an experimental plate reaching the surprising peak of 85 per cent. of all organisms on it in July. In 1934 they were fewer, but large numbers were observed again in September and October, 1935, at the end of the series of researches. Their near monopoly of the experimental surface in 1933 suggests the possibility that they could suppress competition from other sedentary animals without developing fatal rivalry among themselves. However, it is difficult to believe that even if they reached this condition they could maintain it for long, the density of their population being entirely too great for proper sustenance over any considerable period of time in restricted space. It is to be expected that, as in cases of land animals familiar to most of us, a period of high prosperity due to abnormally good supply must result in wholesale destruction due to intensity of competition when supplies decrease to normal or less than normal.

In some respects Bryozoa are the most

¹⁴ Loc. cit.



FIG. 3. THICK, BROAD GIRDLES OF MUSSEL COLONIES SHOWN ON PIER COLUMNS BETWEEN TIDAL LIMITS.

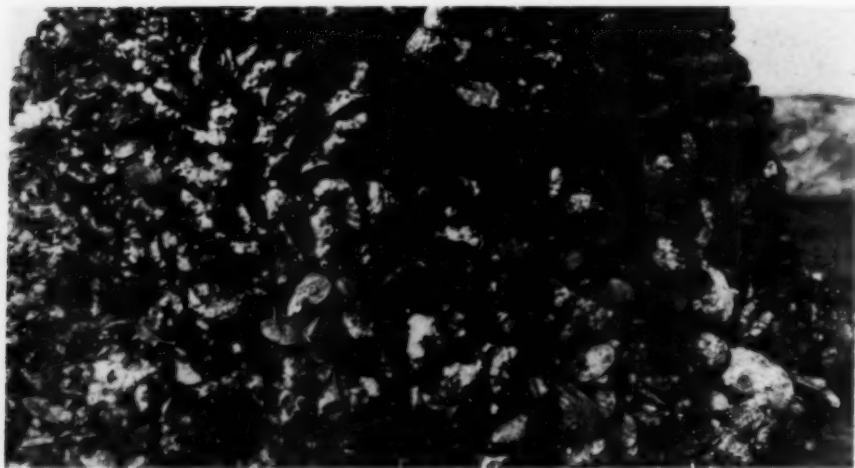


FIG. 4. DETAILS OF EXTREME DENSITY
SHOWN IN COMPETITION FOR PLACE AND SPACE OF MUSSEL AND ASSOCIATED POPULATIONS IN A PIER
COLUMN GIRDLE.

interesting of the many kinds of competitors for space and place on experimental equipment. The two species of *Membranipora*, in particular, are most astonishing because of their ability to win against almost any of the larger, as well as against the smaller, sedentary animals of the inter-tidal zone. Many cases have been noticed in which a colony has spread its thin calcareous crust over single barnacles or groups of barnacles, forming a mantle through which the victims could not thrust their appendages or reach air and sustenance. Perhaps no phenomenon observed among marine animals gives so strong an impression of inexorableness as does the sight of one of these deadly encrustations spreading over prosperous masses of larger animals already resident. When conditions are right for these bryozoans there are few of the shell-building animals which can meet their competition for place.

To any one who has seen the cement columns supporting the pier at the Scripps Institution of Oceanography lack of mention of the salt-water mussels would appear to leave this discussion incomplete. At low tide even a stupid and

untrained observer would be impressed by the enormous girdle of mussel colonies around each column between tidal limits (Fig. 3). On those about a thousand feet from shore all these girdles extend out nearly a foot from the cement surface at the densest part. They are composed mainly of mussels of all sizes from a fraction of an inch to several inches in length, but they also include an amazingly large number of barnacles, oysters, bryozoa, worms, hydroids, algae and other things (Fig. 4). If one had the ability to analyze the differing activities and the genius to trace the interrelationships of the whole assemblage of creatures he would probably find every aspect and every degree of competition between kin and non-kin. Lacking these qualifications, he can still find interesting features easily and quickly. Most prominent is the evidence of competition of mussel against mussel.

No more than among barnacles do mussels respect the rights and interests of their neighbors (Fig. 4). The fact that in most clusters the shells tend to point the same way might suggest that they fix themselves side by side in order to insure

least possible interference of one with another. More probably, this tendency toward uniformity of position is due to orientation to obtain the best available supply of water-borne necessities. Certainly there are plenty of individuals which attach themselves on or about the shell of a neighbor in a position which cuts off most of a regular flow of water. Only the turmoil of waves and breakers prevents the condition from becoming disastrous. So far as the pier is concerned, mussel growth is heaviest on most columns in a section midway between ordinary high-water and low-water marks. The most favorable zone seems to be about two or three feet in depth, not a very promising outlook for larvae liberated by millions to seek lodgings in competition with each other as well as with those already in possession. Nor does the stress of competition seem to be appreciably relieved by success in attachment. As soon as it takes up residence the young mussel finds itself in the midst of a life-and-death struggle to obtain room to grow and to obtain food and air to sustain the growing.

It is well known to biologists that cutthroat competition among kin in nature is not so completely evil as it seems at first thought. The one and only fundamental objective of any and all species is self-perpetuation. Nature rarely tolerates and never encourages development of equilibrium in any kind of population relationships. Usually, there is distinct ebb and flow in prosperity and adversity. To this condition each successful species must adjust and adapt itself. For example, when food is abundant and enemies few it accelerates its growth of population, largely by bringing to maturity great numbers of individuals of inferior strength, hardihood and adaptability. But the species, itself, has no automatic regulator to stop this expansion as a danger point is approached. When the rate of population expansion exceeds

the *rate of supply* of food, or when the rate of diminution of food supply exceeds the rate of adaptability of the population, selective starvation (weakest getting least) operates to take out those weakest or least hardy or least adaptable. Thus the superior part of the population is enabled to survive, cutthroat competition favoring the strong and able as against the weak and incompetent. If the onset of extreme adversity resulted only in all individuals sharing alike, the population would deteriorate, would be unready to take quick advantage of the next period of favoring conditions, and the future of the species would be jeopardized.

If it were not for predatory and parasitic enemies cutthroat competition among kin would be more frequent and deadly than it is. Many populations in nature are reduced to small numbers of hardy, resistant and capable individuals by epidemic diseases, sometimes before intra-specific competition has reached the cutthroat stage. The mussel colonies on the pier at the Scripps Institution show an interesting example of the influence of a predatory animal on development of intra-species competition. Large starfishes are always present on the colonies of the seaward supporting columns, and nearly always it is possible to see within a foot or two on all sides of one a striking array of empty shells of mussels which have been devoured. Perhaps no other kind of example could be found which would show more convincingly the influence of a predator in removing representatives of a species from deadly competition with their fellows.

Horrible as it may appear to some of us, cutthroat competition is yet one of the most important and common of natural phenomena. There exists no way to estimate the value of its influence, but it must be profound. Apparently, some populations are regulated by it almost entirely, although one might have difficulty in proving it for any particular species.



A FIRE IN A FOREST NEAR CORAM, MONTANA

FOREST CONSERVATION AND NATIONAL SECURITY

By RICHARD F. HAMMATT

ASSISTANT TO THE CHIEF, UNITED STATES FOREST SERVICE

CONSERVATION has had many meanings. Theodore Roosevelt gave it body and substance through National Forests; Taft through oil; Wilson through National Parks. Not so long ago it was called "a boon to politicians," "something the public has always approved of" and "the chosen synonym of everything the New Deal is doing."

These are overstatements, but there have been bases for them. Early public-domain and natural-resource scandals involved people of high and low degree. Conservation was one of Theodore Roosevelt's "big sticks." Franklin Roosevelt plays its diapason through a program that includes the Agricultural Adjustment Administration, Soil Conservation Service, Domestic Allotment Act, Taylor Grazing Act, Tennessee Valley Authority, Civilian Conservation Corps, Youth Movement, Farm Security Administration and the Social Security Act.

In one way or another all these have to do with conservation. So the term is now pretty broad. Yet the first resource it was applied to was the forest, and it is in connection with forests that most people think of it. To some of them conservation still means preservation. "Cut not a single tree" is their idea, and they advocate using substitutes in place of wood. Others look at forest conservation as a huge job of reforestation; of planting billions of trees on millions of devastated acres. By larger numbers it is thought of as the physical task of assuring an adequate supply of forest products.

But there is now a deepening concern in its social implications and responsibilities.

This is as it should be, for as a public policy forest conservation's major purpose is to add to human welfare. And this purpose applies to all resources of forest lands and all the many services and functions they perform.

Water from forested slopes is one of those resources. In the West it is the life blood of irrigated crops that enter world-wide as well as national and local markets. Power from water is the backbone of industries that employ hundreds of thousands of people. More than 400 cities and towns depend on domestic water from National Forests alone. Just before the 1936 flood on one of the tributaries of the Susquehanna River, nine tenths of the rain falling on a potato field was lost as run-off. This water carried with it more than 1,000 pounds of soil from every plowed acre. But a neighboring forested area lost only one half of one per cent. of the precipitation, and no soil. Forest cover can not prevent all floods or hold all silt at its source, but this illustration—chosen at random from records of the 12 Forest Experiment Stations through which research activities of the Forest Service are directed—indicates how forest soils help lessen damage by floods and erosion.

Forage is also a forest-land resource. In certain Montana counties with which the writer is familiar a 55-million dollar investment and the livelihood of more than 5,000 people depend largely on use by domestic stock of grass, weeds and browse in local National Forests. Big game populations, receding alarmingly with human settlement, reached an all-time low about the beginning of the



A BARREN 200 SQUARE MILES IN CHIHLI PROVINCE, CHINA
A CENTURY AGO THESE HILLS WERE HEAVILY WOODED, YIELDING RICH REVENUES FROM FOREST PRODUCTS.

present century. But in the National Forests as a whole they have increased 150 per cent. since 1924. More than 1,750,000 big game animals now depend in summer on forage these public properties provide.

Wildlife is therefore a resource in its own right. So is recreation, for forest lands offer priceless spiritual and cultural values to people who, under stresses of modern life, need escape now and then to a more primitive world geared to a slower speed. And forests themselves provide building materials and fuel. Wood yields such things as alcohols and rayons, naval stores and newsprint, perfumes and plastics. Farm woodlands provide forest products each year that are valued at more than 100 millions of dollars. Thirteen million people are supported by workers employed in primary forest industries, in growing forests, in selling and transporting forest products and as wood-working artisans.

With such values and services at stake it seems pertinent to review what has happened to our forest lands and what is happening to them now; and to indicate what part many foresters think forest lands and their resources may play in bringing added security to the nation, and how they may do it.

America has had a wonderful youth. Her growth has been remarkable. Her own population, and foreign demand for her goods and products, have challenged production by labor, by industry and by agriculture. Boldly meeting that challenge, a self-reliant people has established new industries and conquered new frontiers, settled new lands, tapped new supplies of natural resources, and—drained them. The forest was one of those resources.

Ever since Colonial days, when they covered 820 million acres in what, exclusive of Alaska, is now the continental United States, forests have provided food

and clothing and shelter. Larders of Pilgrim Fathers were stocked with venison and wild turkeys. Coonskin caps and fringed buckskin protected scouts and trappers. Trees helped make log cabins and cradles, towns, telephone lines and transcontinental railroads. Forests were vital to the winning of the West and the building of a new nation. Few people thought, in early days, of conserving a resource that then seemed limitless.

Conditions now have changed. As a country we are emerging from our youth. Two hundred years ago people produced slowly, on a small scale, with simple tools operated by hand. Now science gives us complicated machines, and they tend to displace human labor. Two men and a mechanical ditch-digger accomplish what 44 men with shovels once did. To make—and fold—a four-page newspaper used to call for 250 hours of human labor. Thirty years later it required only one hour, thirty-nine minutes and thirty-six seconds. A single mechanical cotton picker can now do the work of 60 to 80 field hands.

By generally accepted standards these things represent progress. Yet estimates indicate that forest drain exceeded forest growth by about 2 to 1 in all sizes, and by about 5 to 1 in saw timber sizes, during the period 1925 to 1929, inclusive. And although we still have 630 million acres of forest land, only 462 million acres are capable of growing commercial forests: of this only 215 million acres now bear trees large enough for saw timber.

These latter figures are based on a nation-wide forest inventory. Undertaken by the Federal Forest Service, its purpose is to find out what forests we have and where they are; how much forest depletion there is, and how and where it takes place; what we need in the way of forest products; how much forest growth we have, and how much we can expect under real protection and management. This inventory, though not yet complete, is far enough along to indicate that:

(1) Although generations hence a few hundreds of thousands of our 630 million acres of forest land may be needed for



THE FALL ROUND-UP IN BEAR VALLEY

PAYETTE NATIONAL FOREST, IDAHO. NATIONAL FORESTS ARE ADMINISTERED ON A MULTIPLE-USE BASIS.



THE WORK OF MAN AND FIRE

THIS AREA NEAR THE KANIKSU NATIONAL FOREST, IDAHO, ONCE GREW FINE FORESTS. AFTER BEING EXPLOITED, IT WAS GUTTED BY FIRE IN 1932.

some other purpose, with minor exceptions most of it is and probably always will be most valuable in forest growth.

(2) From the standpoint of producing lumber, ties, poles, firewood—and newsprint, plastics, distillates, rayons and thousands of other things derived from wood—168 millions of these acres are “out.” Kept in forest growth they help save many farms and cities from erosion and floods; safeguard and help regulate water; provide food and shelter for big game, and opportunities for millions of people to enjoy simple recreation. But because of factors like poor soil and inaccessibility these 168 millions of acres do not now and probably never will produce commercially worth-while forest products.

(3) Of the 462 million acres on which we should be able to count for forest products for human use, 73 million acres have already been so badly cut and

slashed and burned that they are now virtually non-productive. Another 174 million acres now bear trees too small for saw timber, and in general are not heavily enough stocked to produce what they can and should. The balance, 215 million acres, does have trees of saw timber sizes. This area includes our remaining virgin forests. But annual drain of saw timber species and sizes commonly used continues greater than the annual growth of those sizes and species.

This doesn't seem particularly reassuring. There are conditions that make it less so. The best three fourths of all commercial forest land is in private ownership, and most operations on these lands are still geared to practices that threaten the existence—or the stability—of community after community.

This is not true of all these operations. In northern Mississippi and southern

Arkansas, for example, the writer has seen some of which any one might well be proud. Instead of being mined, these forests are cropped and renewed, and in this process forest growth is increased. But although credit is due these leaders they are—with or without their knowledge and consent—being used as a smoke screen by that big majority of operators and owners that still clings to quick liquidation: to that old cut-out-and-get-out practice that has been responsible for ghost towns—and human misery—from the Catskills to the Cascades and from Canada to Mexico.

This is the practice that in large measure has also been responsible for shortages of valuable species and grades once produced in abundance in many localities and regions. Many of these regions and localities still have forests of a kind, and still produce forest products. But output is in large part confined to less desir-

able species and grades, and is often insufficient to meet local needs. Under these conditions many regions and localities now use less than they really need; import little because (with hauls so long that transportation sometimes doubles the price) many forest products are luxuries to people who have most of the buying power.

The forest inventory indicates, however, certain mitigating conditions. The 73 million acres previously mentioned are still *capable* of producing commercially valuable forests. Annual growth can be speeded up on the 174 million acres that now bear trees too small for saw timber. And both this area and the 215 million acres that still have saw-timber trees are *capable* of producing much more than they now do.

These and related facts seem to warrant the belief that unless abuse and neglect continue we probably have enough



VIRGIN TIMBER IN THE COEUR D'ALENE NATIONAL FOREST, IDAHO



A FIRE OBSERVATION TOWER
LOOKOUT (WITH GLASSES) AND SMOKE-CHASER
(READY TO GO) LOCATE FIRE FROM JACK-KNIFE
RIDGE, COEUR D'ALENE NATIONAL FOREST, IDAHO.



WHITE BIRCHES IN NORTHERN MINNE-
SOTA

forest land; that with care and forethought—with a forest policy and action programs geared to current conditions and future needs—there need be no excuse for a timber shortage of national proportions. They also indicate a way out for hundreds of thousands of families suffering now for lack of work. For forest restoration and improvement of forest stands could provide work for these people. And the one could make idle lands productive again; the other could increase growth, and the proportion of the more valuable species in the stand. The two, through forest work, could create new wealth.

The extent to which this might be done is hinted at by certain investigations conducted in loblolly pine (*Pinus taeda*) in Arkansas. Briefly, Mr. Henry Bull, silviculturist at the Southern Forest Experiment Station, has determined that with the current average degree of understocking, an acre of loblolly pine in Arkansas will produce 4.5 times as much cellulose per acre as the average acre of cotton does; that if fully stocked and fully producing, the average acre of loblolly pine in Arkansas will produce 11 times as much cellulose per acre as is produced on the average acre of cotton.

The part forests have played in our national income and the part they can be expected to play in future income also indicates the extent to which more and better forests might create new wealth.

Figured as the money equivalent of goods produced and services rendered, the total national income was approximately 80 billions of dollars in 1929. Disregarding certain intangible benefits from forests, but including cash values for wood products, for water conservation and for wildlife and livestock production, about 3 billions of our 1929 national income can be credited to forest lands.

Contributions forest lands can make after rehabilitation and development

have become effective must be evaluated on the basis of certain assumptions that as time goes on will be subject to many influences and interpretations. Such an evaluation, though it can not be made too closely, points to significant probabilities. One is that the national income from forest lands and forest products may be increased by some 2.4 billions of dollars a year. A second: the work of restoration and rehabilitation can be accomplished within two decades. A third: this work can be accomplished by an annual investment equivalent to less than 3 per cent. of our yearly retail sales of automobiles and accessories. A fourth: applied to rural populations in need of part-time jobs, this investment could provide 20 years of constructive work for people who, with their dependents, represent 1,000,000 people.

Still another probability is that, although conditions and opportunities for early returns vary as between regions and localities, once forest lands are restored and improved they can—within areas from which much of our future population will come—assure more stable and better standards of living by providing *continuous* forest crops. But this objective depends, as does insurance against a timber shortage of national proportions, on adopting and conforming to a more adequate forest policy and more adequate action programs than those we now have.

An adequate forest policy for the nation must recognize, according to Dr. F. A. Silcox:¹

(a) That our 630 million acres of forest land are and probably always will be more valuable in forest growth than for plow land or any other purpose.

(b) That this area must be adequately protected against damage or destruction by fire, insects, diseases and quick liquidation, and that on it adequate forest and

¹ Report of the Chief of the Forest Service, 1938.

other cover must where necessary be restored and maintained.

(c) That, in addition, growing stock and productivity must be built up and maintained on the 462 million acres of commercial forest land.

(d) That protection must be assured to private owners who comply with the nation's forest policy, and to those public interests that are inherent in all forest lands no matter who owns them.



PLANTING PONDEROSA PINE SEED-LINGS

IN COLORADO. TO GROW COMMERCIAL TIMBER AGAIN. FOUR AND ONE HALF MILLION ACRES NEED REFORESTING IN NATIONAL FORESTS ALONE.

(e) That research is basic to full and continuous use of all products and values and services that forest lands and their resources can render locally, nationally and through world-wide markets.

(f) That since the forest resource is inextricably bound up with use of land for other crops, forest lands and their resources should be managed as integral



SELECTIVE CUTTING IN LODGEPOLE PINE
 PROVIDES IMMEDIATE REVENUE, BUT LEAVES MANY TREES FOR FUTURE CROPS. DEERLODGE NATIONAL
 FOREST, MONTANA.

parts of a unified agricultural pattern contributing to local and national structures and to social as well as economic ones.

President Roosevelt has suggested the need for an action program for forest lands. His suggestions² include (1) public cooperation with private owners, (2) public regulation of cutting practices on privately owned forest land, (3) extension of public ownership and management.

Public cooperation is essential because although private owners must in the public welfare conform to the forest policy for the nation, the public—through State and Federal Governments—must also recognize and redeem its responsibilities and obligations.

Forest fires illustrate some of these public obligations and responsibilities.

² Document No. 539, dated March 14, 1938, addressed to the 75th Congress, 3d Session.

For although lightning sets forest fires, most of them are man-caused. Witness the 1937 record. Lightning, 31,000; human beings, 170,000. Most of the latter were the result of carelessness by campers, hunters and fishermen, but on the National Forests nearly one fourth were of incendiary origin.

Since it should be possible to eliminate most man-caused fires, the first step in forest fire protection is prevention. This is a field within which the Advisory Council on Human Relationships, recently created by the American Association for the Advancement of Science, will, it is hoped, offer expert advice and assistance.

Forest fire protection also requires lookouts to detect forest fires, telephone lines and radio to report them, roads, trails, landing fields, tools and supplies, so crews can be equipped, get to and suppress fires without delay. In all this,



BIG SAND LAKE IN THE LOLA NATIONAL FOREST, MONTANA

THERE ARE THIRTY NATIONAL-FOREST PRIMITIVE AREAS. WITHOUT ROADS, HOT-DOG STANDS, ETC., THEY EMBRACE MORE THAN SEVENTEEN MILLION ACRES.

federal and state cooperation with private owners has brought real progress in the last 12 years. The area of state and private land under organized protection increased to almost 302,000,000 acres, and the area burned decreased by more than 1,600,000 acres. But nearly 70 per cent. of the 1937 fires and 95 per cent. of the area burned were on more than 182,000,000 acres that—for lack of adequate federal, state and private funds—are still outside organized fire protection districts.

The forest inventory—on which industry as well as federal, state and local governments are drawing—is not yet completed, and there is also need for extension of public cooperation with respect to such things as forest credits, taxation of forest lands and research.

Private credits to forest industries have in the past tended to force quick liquidation of the basic resource. Public

or publicly sponsored credits (like those administered by the Farm Credit and Federal Housing Administration) should—if extended to owners who comply with the nation's forest policy—help protect public interests and aid industry. So might revision or modification of the present system of timber-land taxation, for it also tends toward quick liquidation practices.

Most forest and allied research in the United States centers in and forms a major responsibility of the Forest Service. Its object is to develop technical and economic bases essential for the intelligent use of forest land and its resources in private as well as public ownership. This requires a wide range of information about hundreds of tree species occurring in an infinite variety of combinations and type conditions; of growing conditions in climate that varies from tropical to arctic



PULPWOOD THINNINGS IN 37-YEAR-OLD SHORTLEAF AND LOBLOLLY PINE IN ARKANSAS. EIGHT CORDS PER ACRE HAVE BEEN REMOVED, LEAVING 20 CORDS GROWING FOR MORE VALUABLE POLES, PILING, SAWLOGS.



TENNESSEE LAND ONCE WELL FORESTED
EROSION, FOLLOWING KILLING OF VEGETATIVE COVER BY COPPER SMELTER FUMES, HAS ALSO EXTENDED INTO THE GRASS ZONE.

and from rainbelt to desert; of many soils and many exposures; and of science in relation to social problems.

Research has contributed extensively to progress in forest conservation, but there is still a large gap between what is known, what needs to be known and how it should be applied if one third of the land area of the United States is to contribute its fair share of raw materials, supply profitable and useful employment for thousands of workers in woods, mills and allied industries using wood, and play the role it should in regulating stream-flow and controlling floods.

Private ownership is part and parcel of democracy as we know it, but forest lands have values and contribute services that are far greater to 130 millions of people than they are to the few thousands who now own most of the best of them. Private initiative and public cooperation have brought worth-while advances in forest conservation, but exploitation is still the rule rather than the exception among operations on privately owned forest lands in the United States.³ And human exploitation still follows forest exploitation just as surely as night follows day.

If public ownership is not acceptable as an alternative, these conditions point to some form of regulation of cutting practices. And since neither in the United States nor in any other country has purely voluntary action succeeded in applying sustained yield management to forest lands generally, *public* regulation seems indicated.

³ According to *The New York Times* for February 23, 1939, George H. Gibson of the Mosinee Paper Mills Company, speaking at a recent meeting of the National Paper Trade Association, said: "There is no reforestation worthy of the name being practiced in this whole wide country of ours. There will be none," he added, "until a terrific public opinion demands from this government that they take over and limit the cutting of the woods of the country not to exceed their annual growth."

Dr. Silcox warns, however, that to safeguard our democratic pattern such public regulation "must come as a result of standards openly arrived at. These standards," he says,⁴ "must reflect local needs and conditions. They must be flexible and fair. They must protect both local and nation-wide values and services; conserve broad public interests; safeguard those of dependent communities and private owners; provide for decentralized and understanding application; make court action unnecessary, except as a last resort, by assuring the right to arbitration and appeal."

Private ownership of forest lands antedates the Revolution, but public ownership and management are now established policies. They already apply to community forests, state forests and National Forests.

Community forests—there are about 1,500 of them in 20 or more states, with a total area in excess of 3 million acres—protect water supplies, provide opportunities for inspiration and inexpensive outdoor recreation, improve hunting and fishing, and grow timber for municipal and other uses. Demonstrating that, managed on a cropping basis, the forest can be used for all these things, most of them illustrate essential differences between forests and parks. They also afford local opportunities for replacing a public dole by worth-while work that increases the services and values derived by the public from these public properties.

Like community forests, organized state forests are generally managed on a multiple-use basis. They are, in this respect, distinct from state parks. Most of the 800 organized state forests in 41 states—with nearly 11 million acres of state-owned land—are not quite so near large centers of population, but many

⁴ "A Federal Plan for Forest Regulation within the Democratic Pattern."



KENTUCKY LAND PLANTED TO YELLOW POPLAR TWO DECADES AGO
ONCE IDLE AND UNFIT TO PLOW, IT NOW PRODUCES NEW WEALTH.

states plan to have them so well and widely distributed that the public will ultimately have ready access to them.

National Forests are located on the flanks of the Appalachians from New Hampshire to Georgia, around the Great Lakes and headwaters of rivers like the Mississippi and Missouri, on the Great Smokies, in southern pineries and—between Canada and Mexico—on the slopes of the Rocky, the Cascade, the Sierra Nevada and the Coast Ranges. They include nearly 176 million acres of federally owned land. Established irrespective of state boundaries, these public properties are distinct from National Parks in that they are administered on a multiple-use basis, with use as well as renewal of all their resources and values.

The national-forest system is interstate. It offers striking contrasts between civilization and wilderness, industrial activities and pastoral, material values and spiritual ones. More than 1,280 million

feet of timber was harvested from it, under provisions that assure continuity of the forest stand, in 1938. It already provides a living for almost a million people, but it also provides recreation for 30 million each year. It is home and refuge for most of our remaining big game, but also furnishes forage for more than 6,857,000 domestic live stock, and helps prevent floods and erosion. It includes some 70,000 miles of fishing streams and more than 3,500 developed public campgrounds, yet it provides domestic water for 6 million city people. And although they have 30 primitive areas embracing 17,000,000 acres, the National Forests also have a public transportation system that includes more than 138,000 miles of highways and roads and 153,000 miles of trails.

The extent to which, with due regard to private ownership and initiative, community, state and federal ownership and management of forest lands might ulti-

mately be increased was placed before Congress, at its request, in 1920 and 1933. In 1934 this problem was analyzed by the National Resources Board, which suggested a long-time program involving some 190 million acres. Field examinations by the Forest Service in 1937 suggest that community and state ownership and management might be extended to 48 million acres, and that federal ownership and management might be extended to 59 million acres. Of the latter, 40 million are private land within boundaries of existing National Forests; 19 million acres, outside those boundaries, are vital to problems interstate in character and scope.

Federal ownership—existing as well as proposed—poses the question of compensation to states and counties for loss of tax revenue. The Federal Government has as yet no consistent policy with respect to this problem. No compensation

is made for millions of acres, yet for the National Forests 25 per cent. of the gross receipts are returned to states and counties. Based solely on current income, this provides little if any immediate returns from lands that, heavily cut by private owners, have been or may be purchased by the Federal Government. Fortunately there is recognition that this situation is unsatisfactory, and Senator Harrison, of Mississippi, has introduced legislation to remedy it.

Civilizations the world over are dependent on land and water. If nations are to be permanently prosperous and secure, these basic resources, and the living ones from which they spring, must be used wisely and well. Forests are one of these resources. It has been said that the chief causes of the decline of certain early civilizations were deforestation and denudation of hillside soil rather than changes of climate or attacks by bar-



FIELD AND FOREST IN WEST VIRGINIA

THIS VIEW OF NORTHFORK VALLEY, MONONGAHELA NATIONAL FOREST, ILLUSTRATES CLOSE RELATIONSHIPS BETWEEN FOREST AND FLOWLAND CROPS.

barians. Whether or not this be true, it is known that the north coasts of Africa and Palestine were once well forested, but forests and civilizations there are at a low ebb now. It is also known that China once had great forest wealth, but that to-day it is almost treeless and its people are forced to use dung for fuel.

"Out of the forest came the might of America; wealth, and power, and men."⁵ There is truth in this statement by Jenks Cameron, but out of those same forests have in large part come our distressed rural regions. With minor exceptions these include 1,300 counties, half of all our farms, millions of acres of tax-delinquent land. Index of average farm income is under 30 compared with 90 to 120 for typical corn belt counties. Living standards are low, educational facilities meager. There are 700 to 1,000 children under 5 years old for every 1,000 women

⁵ "Development of Governmental Forest Control in the United States." Published by the Johns Hopkins Press, 1928.

of child-bearing age. Undernourishment and pellagra are common.

But 60 odd per cent. of the land in these distressed regions is more valuable in forest growth than it is as plow land. These lands once grew forests. They have been abused, but forests can be restored on them. Cropped instead of mined, new forest wealth can provide better standards of living for hundreds of thousands of families now in sore distress; and add to national security.

What has happened to our forest lands and what is happening to them now indicate that it may be no light task for a nation to stop forest and human exploitation, and to provide affirmatively for forest and human rehabilitation. Yet what has been done on the National Forests, and what is now being done on their own lands by leaders in forest industries, indicate that the job *can* be done. And the values at stake seem to make it a worth-while one.

THE BENLD METEORITE

By Dr. H. W. NICHOLS

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THE meteorite which fell at Benld, Maecoupin County, Illinois, on September 29 of last year is of unusual interest, as it is one of the few—there are only eleven of them—which are certainly known to have struck and damaged property. At nine o'clock in the morning this meteorite crashed through the roof of a garage owned by Ed. McCain and, after penetrating the roof of his Pontiac coupe, passed through the seat cushion and after striking and denting the muffler, rebounded and came to rest tangled in the springs of the seat cushion. Two members of the Joliet Astronomical Society, Ben Hur Wilson and Frank M. Preucil, secured the meteorite for Field Museum of Natural History in Chicago. The meteorite, accompanied by the damaged parts of the car and roof, is now a part of Field Museum's important meteorite collection.

As reports of finds or falls of meteorites are almost invariably either without foundation or otherwise erroneous, Wilson and Preucil were naturally skeptical of the first reports. Nevertheless, they entered into correspondence with Mr. McCain and others in Benld which soon convinced them that the report might possibly be correct. They were unable to visit Benld until October 29, more than a month after the fall, but found that Mr. McCain had carefully preserved the meteorite and kept undisturbed the damaged car and garage. At Benld they made unusually complete and competent notes and took numerous photographs. Their observations have been published in full in *Popular Astronomy*.¹

¹ Ben Hur Wilson, *Popular Astronomy*, 46: 548, 1939.

No one actually saw the meteorite fall, but the time was determined by the loud roar it made, which startled Mrs. McCain and a neighbor and was heard less distinctly by several others. The neighbor, Mrs. Carl C. Crumb, was in her back yard barely fifty feet from the garage. She was startled by a great roar like that of a plane in a power dive. This roar, which lasted only an instant, was followed by a sharp cracking sound like the breaking of boards. She rushed into the alley expecting to find the roof or side of her barn crushed by a fallen plane, but found no damage nor was there any plane in sight. She places the time between 9:00 and 9:10 o'clock in the morning. Mrs. McCain, in her yard but not as near the garage as was Mrs. Crumb, also heard the roar but paid little attention, as she took it to be the sound of a passing plane. No fumes, smoke or odor was detected by Mrs. Crumb, but another neighbor, Mrs. Lindy Brown, said she plainly detected an odor of sulfur (ozone?).

The fall of a meteorite is frequently accompanied by loud detonations, due to the meteorite bursting in the air. No detonation was heard by Mrs. Crumb or Mrs. McCain and, as such explosions are very loud, if the meteorite burst in the lower part of its path the sound would certainly have been heard.

The damage was not discovered until late, in the afternoon, when Mr. McCain entered the garage to get his car. The roof penetrated was of pine board with a "tar paper" cover. The meteorite broke a hole, clean on the outside but splintered on the inside. The hole is rectangular, about 4 by 5 inches in size. It is slightly too small for the meteorite to pass



THE BENLD METEORITE

through, indicating that the board bent under the impact. The stone made a clean hole through the roof of the car. The hole through the seat is ragged, owing to the nature of the material. The dent on the muffler is only an inch deep, indicating that the stone had lost most of its energy before it reached the muffler. Where the stone came to rest after rebounding into the seat it was so entangled in the springs that they had to be cut before the meteorite could be removed. Examination of the cotton filling of the seat where it was in contact with the stone shows not the slightest indication of charring. This proves that the meteorite could not have been hot when it fell. This was to be expected, for those meteorites which have been picked up immediately after their fall have been only lukewarm. It is unusual to find one too hot to hold comfortably in the hand.

As two points in the path of the stone were known, the point where it penetrated the roof and the point where it penetrated the seat cushion, Wilson and Preucil were able, by the use of a surveying instrument, to determine with pre-

cision the azimuth and inclination of its path at the end of its travel. This is the first time such an accurate measurement has been possible for any meteorite. When the meteorite struck it was moving in a course $64^{\circ} 26'$ east of north in a path inclined $77^{\circ} 31'$ to the horizontal.

The meteorite is a roughly rectangular block $4\frac{1}{2}$ inches long, $3\frac{1}{2}$ inches wide and $3\frac{1}{4}$ inches thick. It weighs 1,770 grams, or about four pounds. It is a stony meteorite or aerolite. To which of the numerous sub-classes of aerolites it belongs has not yet been determined, but it will probably be classed as a veined gray chondrite. It is light gray in the interior with a porous granular texture and is covered with a thin black fused crust developed by friction during its passage through the air.

An account of the changes undergone by this meteorite during the few seconds of its passage through the air may be of interest. No one knows where or how meteorites originate. The older theories, such as that they come from volcanoes, the moon or sun, have long been discredited. A more recent theory that they are fragments of comets seemed for a time sufficient. This is the origin that seems most probable for the periodic swarms of shooting stars and for many of the other shooting stars which are meteoritic particles too small to pass through the atmosphere without being consumed, but there are reasons to believe that some other origin must be sought for the aggregations of meteoritic material which are large enough to reach the ground without being utterly consumed. There are indications that meteorites are fragments from larger bodies, but theories of their origin remain highly speculative. Some have orbits entirely within the solar system, others are visitors from outer space. If some one at a distance from Benld saw the meteorite as a passing meteor and noted its position and the direction of its

flight it may be possible to determine its orbit. This has been done for a few other meteorites.

Before the meteorite reached the air it was a gray body of unknown shape without the dark crust it now has. It was much larger, for during its passage through the air it lost the greater part of its weight. Wastage from friction during its passage through the air is so great that the Italian astronomer, Schiaparelli, computed that a stone meteorite, such as this, must have a diameter of at least eight feet if any portion of it is to reach the surface of the earth.

The velocity of its approach was enormously greater than its speed when it struck the garage. Meteorites striking during the morning hours collide with the earth head on so that the velocity relative to the earth is the sum of the veloc-

ities of earth and meteorite in their orbits. This velocity is of the order of forty-four miles per second. If the Benld meteorite had retained this speed until it struck, the consequences would have been disastrous, for even if it had only its final weight of four pounds it would have struck a blow in excess of 2,000,000 foot tons. Even the extremely rarefied upper atmosphere opposes so great a resistance to the passage of a body moving at such an enormous speed that its speed is rapidly moderated, and while it is still several miles above the surface its velocity has been reduced to that of a similar body falling under the influence of gravity alone. This is the speed at which the acceleration of gravity is balanced by the resistance of the air. In the case of the Benld meteorite it was probably between 400 and 500 feet a second. Most of its lost energy of motion



GARAGE WITH METEORITE ON THE ROOF IT PASSED THROUGH

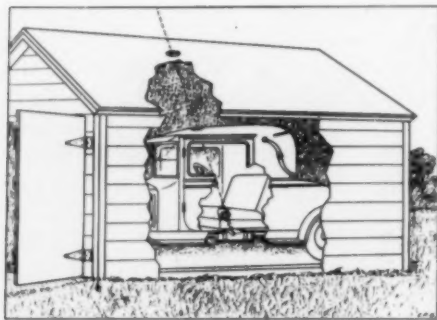


DIAGRAM OF METEORITE PATH

was converted into heat by friction between the surface of the rapidly moving meteorite and the air. The surface became incandescent, melted and in part vaporized. The rush of the meteorite through the air washed away the heated surface as fast as it softened or melted, bringing more of the meteorite to the surface to be in turn heated and washed away to trail behind as a luminous train. Only a thin coating of the melted material remains to cover the meteorite with a dark crust.

As a meteorite first appears high in the air as a glowing meteor, there appears to be a general belief that a meteorite must be intensely hot when it strikes. But the



DAMAGE BY METEORITE
MAY BE REPRESENTED BY THIS OLD WOODCUT.

friction-heated surface is washed away as fast as it forms, the body of the meteorite is intensely cold and there are only a few seconds available for heat to penetrate to the interior. During the last few miles of its descent its velocity has been so reduced that the friction developed is no longer sufficient to heat the surface, the luminous phenomena disappear and the hot surface cools so rapidly that the meteorite is seldom more than lukewarm when it strikes, although a few have been too hot to be comfortably handled. Reduction of velocity during its passage through the air is so rapid that enormous strains develop which cause many meteorites to burst. The angular shape of the Benld meteorite suggests that it may have burst, but as no sound of explosion was heard at Benld, if it burst at all, it did so high in the air many miles from where it struck. If it did burst, other individuals from it may be found possibly at a distance of several miles from where it struck.

The fall of the Benld meteorite calls attention to the danger, ever present and not to be guarded against, of injury to person or property from falling meteorites. Although this danger is always present the records show that peril from this source is so slight as to be negligible. The late Dr. Farrington, formerly head of the Department of Geology of Field Museum of Natural History and one of the world's leading authorities on meteorites, stated in his book "Meteorites:"²

No meteorite fall has ever positively been known to have been destructive to human life. Accounts purporting to describe such catastrophes prove on investigation to have come either from times or countries so remote that that they can not be verified. Many accounts of such an occurrence come to us from earlier times and the scene here pictured probably illustrates destruction believed by an early artist to have been caused by meteoric stones falling from the skies. But no well-authenticated occurrence of

² O. C. Farrington, "Meteorites," p. 28, 1915.



DAMAGED CAR WITH ED. MCCAIN HOLDING METEORITE

the sort is known. Perhaps the most narrow escape which has ever been experienced was that of three children in Braunau at the time of the fall of that meteorite in 1847. This meteorite, an iron weighing nearly forty pounds, fell in a room where these children were sleeping and covered them with debris, but they suffered no serious injury. Other meteorites have fallen near human beings but never have struck them so far as credible information goes. That personal injury or death might be caused by the fall of a meteorite is entirely possible, in fact is likely to occur at some time. It is remarkable that some falls, such for instance as the showers in Iowa which occurred in fairly thickly settled communities, should not have caused serious injury to the inhabitants.

There are a few probable but not proven instances of animals being hit. During the past 150 years during which records have been kept only eleven meteorites are certainly known to have penetrated buildings. The first recorded damage to a building occurred at Barbotan, France, in 1790. Other damage to buildings was occasioned by meteorites which fell at Benares, India, in 1798; Massing, Bavaria, in 1803; Braunau, then in Ba-

varia, in 1847; Aussun, France, in 1858; Pillistfer, Lativa, in 1863; Kilbourn, Wisconsin, in 1911; Baxter, Missouri, in 1916; Kurumi, Japan, in 1930; Yurtusk, Ukraine, U.S.S.R., in 1936, and Benld, Illinois, in 1938. Fragments of eight of these are in the collection of Field Museum. The collection also has a roof board penetrated by the meteorite which struck a barn in Kilbourn, Wisconsin, on June 16, 1911. The stone passed through three thicknesses of shingles, a hemlock roof board and the plank floor of a hay loft. It then glanced against the side of a manger and buried itself two and one-half inches deep in the clay floor of the barn. There is also the branch of a tree, barked by a meteorite which fell in Andover, Maine, on August 5, 1908. There are also a few instances where damage by meteorites seems probable but can not be proven. A recent example is the fall of a meteorite in Pennsylvania among the cattle on a farm. Later one of the cows was found to be seriously injured, as if it had been struck by the meteorite. It is

probable that the meteorite struck the cow a glancing blow, but as there are many ways in which cattle can be injured this conclusion can not be accepted as absolutely certain. The frequent newspaper accounts of injury are always investigated and prove with few exceptions to be without foundation. Some of them are absolutely baseless, others are the results of mistaken interpretation of the cause of the damage, and others are deliberate fakes. An example of mistaken interpretation was the case that came to the attention of Field Museum many years ago of a woman while in her back yard being struck on the head by a small meteorite. The alleged meteorite proved to be an ordinary pebble and an investigation showed that, as the woman was much disliked by the children of the neighborhood, it is probable that she was hit by a stone thrown by one of the children. An example of a deliberate hoax is a report from Crawfordsville, Indiana, where it was claimed that a meteorite struck a Ford car and passed through its hood. Investigation showed that the damage was oc-

casioned by the accidental discharge of a gun and a meteorite hoax was invented by boys to avoid liability for the damage.

A calculation by Dr. H. H. Nininger, of the Society for Research on Meteorites,³ shows how exceedingly slight is this danger from falling meteorites. He found that for the 125 years preceding 1925 there were, in twelve European and American countries, for which fairly good records have been kept, 287 witnessed falls, from which 129,349 individual meteorites have been recovered. The area of the countries involved is 7,205,503 square miles. These figures show that one meteorite from a witnessed fall fell for each fifty-five and one-half square miles of surface. But many meteorites fall unseen. Dr. Nininger, arbitrarily assuming that ten times as many meteorites fell as were reported, a reasonable figure, estimates that in 125 years one meteorite fell for each five and one-half square miles. When we consider how small an area is covered by living human beings it is not surprising that no one has as yet been

³ H. H. Nininger, "Our Stone Pelted Planet," p. 78, 1933.



METEORITE WITH DAMAGED PARTS OF CAR AND GARAGE IN FIELD MUSEUM

injured. The area covered by buildings is of course larger but yet so small that the wonder is not how few but how many buildings have been struck.

It is only the exceptional meteorite, one out of many millions, that is large enough for any part of it to survive the wastage of its passage through the air. When such a meteorite strikes, its size and velocity have been so greatly reduced that the impact is relatively harmless. Even more exceptional are the few that have made the meteoric craters like that at Canyon Diablo, Arizona, which is three quarters of a mile in diameter and 570 feet deep. These are so enormous that they are little impeded by the resistance of the air, and when they hit they excavate huge craters like those from the explosion of military mines. Only eight of these are certainly known to have fallen in recent geological times. There are a number of other craters the origin of which is

disputed, but adding these and probable future finds to the eight will not more than double the number.

The earth is daily bombarded by millions of meteorites so small that they are completely consumed in the upper air, miles above the solid surface. These are perceived only as luminous trails of shooting stars and meteors. Most of these trails are so faint that they may be seen only through powerful telescopes. The great majority of them weigh from a few ounces to a fraction of a grain, but even a particle weighing less than a grain moving with the original velocity of a meteorite would pass completely through a human being. We would have, were it not for our atmospheric protection, instead of an occasional trivial damage, as exemplified by the Benld meteorite, an aerial bombardment so severe that animal life could not exist except in the depths of the sea.

THE ORIGIN OF IGNEOUS ROCKS AND THEIR MINERAL CONSTITUENTS

By Dr. J. F. SCHAIRER

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON

SINCE the beginnings of human history, man has noticed the rocks on the surface of the earth and wondered whence they came. Rocks originating from hot, molten materials were observed in very early times in the Mediterranean region. Flows of hot lava poured from active volcanoes, devastating the countryside and terrifying the inhabitants. When these lavas cooled, new rocks, which were called igneous or fire rocks, covered the areas of the flows. Also, hot volcanic ash and breccia were blown from the volcanic craters and showered on the neighborhood. Hot springs, fumaroles and solfataras showed that in other places heated materials came from within the earth. But only during the past century and a half have scientists obtained a clear picture of the nature of the processes and of some of the physical and chemical principles which underlie the formation of the igneous rocks.

NATURE OF ROCKS

A rock is usually an aggregation of minerals, but this is not a broad enough or a wholly correct definition. Rocks may be composed entirely of minerals or entirely of glass or partly of both. A mineral is a chemical element or compound which occurs in nature. Glasses are merely chilled molten masses which have not crystallized into one or more definite minerals. In ordinary usage, a rock is something hard and firm, but in geology the word rock does not have this limitation, for a soft layer of volcanic ash or dust is also a rock. A rock is one of the integral components of the earth's solid shell. Rock of a particular kind implies a certain constancy of chemical and mineral composition. Thus, a large or small

mass of granite is a recognized kind of rock, but a chance filling of a mineral vein by variable amounts of ore minerals is not accepted by petrographers as forming a definite rock. According to ordinary geological usage, a particular kind of rock must possess definite boundaries and show by its relations to other rock masses that it owes its existence to definite geological processes. The size of a rock mass is not important, for a seam or dike of granite or basalt cutting rocks of other kinds may be as thin as cardboard or a mile in thickness.

Rocks may be divided into three general classes according to their mode of origin: (1) *igneous rocks*, derived from a molten magma; (2) *sedimentary rocks*, derived from detrital material; and (3) *metamorphic rocks*, formed from the other two classes by physical or chemical processes.

The igneous rocks are the primary rocks of the earth's shell, because from them *all* other rocks have been derived by weathering, disintegration, transportation, chemical or physical changes and other generally similar processes. In a broad sense, the chemistry of the igneous rocks is the chemistry of the earth's primary crust.

ROCK MAGMAS

The ultimate source of an igneous rock is its parent magma—a molten solution of complex silicates with smaller amounts of the less abundant chemical elements and compounds of the earth's mass. Rocks are formed from this parent magma by a crystallization, in whole or in part, of this molten solution. Minerals do not crystallize from a magma in the order of their fusibility, but follow much

more complex laws which we shall discuss later. The complex crystallization processes by which a magma may yield many different kinds of igneous rock is known as magmatic differentiation. This process follows definite physical and chemical laws operating on a large scale in the earth.

Many of the ore deposits of the world are closely connected with the igneous rocks. In order to outline the process of their development, let us assume that there is a large body of molten magma in a subterranean reservoir. On cooling, crystallization begins and a large part of the mass crystallizes to form igneous rocks. By reason of selective crystallization, those chemical constituents which are present in the largest amount or are most insoluble are first removed from the solution to form igneous rocks. Gradually there is a concentration of rare or more soluble constituents and of water and gases in the residual solution. Valuable metals concentrated in this way may be

later deposited in veins or fissures in the already cooled igneous rocks or in the surrounding rocks, thus producing important ore deposits.

In volcanoes and volcanic fissures we often see molten lavas which actually reach the surface of the earth. A picture of the lava pit at Kilauea in Hawaii is given as Fig. 1. We know, however, from geological studies all over the world that very much larger amounts of molten magma come up from the interior of the earth into its outer zones, and there cool slowly and crystallize without ever actually reaching the surface. The rocks formed from these deep-seated magmas are not exposed generally until after many millions of years, when the overlying rocks have been removed by erosion.

CHEMICAL COMPOSITION OF THE IGNEOUS ROCKS

Of the ninety-two fundamental elements known to chemists, ten make up about 99 per cent. of the igneous rocks.



(Photo by E. S. Shepherd.)

FIG. 1. VIEW INTO THE CRATER, HALEMAU MAU, AT KILAUEA, HAWAII, SHOWING MOLTEN LAVA.

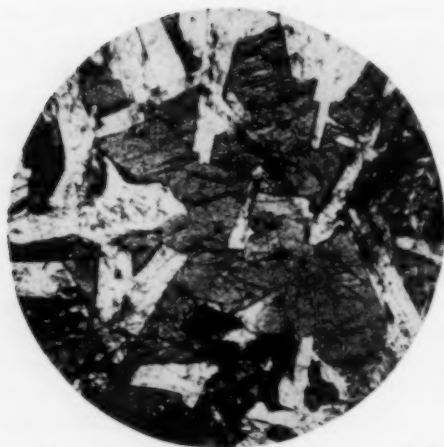


FIG. 2. THIN SECTION OF IGNEOUS ROCK (DIABASE) SHOWING CRYSTALS OF PLAGIOCLASE, AUGITE AND MAGNETITE.

In the minerals of the igneous rocks, as in the magmas, most of the elements occur combined with oxygen. Magmas are silicate solutions, that is, molten masses of the various oxides of the metals combined with silica (oxide of silicon), SiO_2 . The average composition of the igneous rocks expressed as oxides is given in Table I.

TABLE I
AVERAGE COMPOSITION OF IGNEOUS ROCKS

Oxides	Percentage
Silica (SiO_2)	59.12
Alumina (Al_2O_3)	15.34
Ferric (Fe_2O_3)	3.08
Ferrous (FeO)	3.80
Lime (CaO)	5.08
Soda (Na_2O)	3.84
Magnesia (MgO)	3.49
Potassia (K_2O)	3.13
Water (H_2O)	1.15
Titania (TiO_2)	1.05
Phosphoric (P_2O_5)	0.30
Manganous (MnO)	0.12
All others	0.50
	100.00

In considering the principles involved in the origin of the igneous rocks, we shall confine ourselves to the chemistry of the first ten oxides of Table I.

MINERAL COMPOSITION OF THE IGNEOUS ROCKS

Most of the igneous rocks are made up

of crystalline chemical compounds, called minerals. A knowledge of these minerals is essential before any attempt is made to trace their origin. The petrologist, through a study of thin sections (see Fig. 2) of a large number of rock types and the relations of rocks to each other in the field, has acquired a large amount of information concerning rocks and minerals which must form the background of any inquiry into the physical and chemical processes involved in their origin.

One igneous rock may consist of grains so large that the individual minerals may be easily distinguished and identified, whereas in another the grains may be so small as to preclude identification except with a microscope or x-rays. The mineral grains may be of uniform size or the rock may consist of a few large crystals embedded in a ground mass of tiny mineral grains. The petrologist obtains clues to events in the history of the rock from such textures or from larger-scale zonings in rock series. For example, in certain of the lavas most of the rock is a black glass with a few crystals of the mineral pyroxene, so oriented in the glass as to indicate the flow lines of the moving lava stream. Other bodies of igneous rock show signs of zoning, indicating that certain minerals have settled toward the bottom or floated upward in the lava stream or magma chamber. Etched or corroded crystals indicate that minerals, stable at one stage, became unstable in a subsequent stage and were redissolved, in whole or in part, or transformed to other minerals. These examples and many other such observations on minerals and rocks suggest the nature of the physical and chemical processes that were in operation in their formation.

The most important and common minerals of the igneous rocks are given in Table II.

THE PROBLEM OF ORIGINS

We have been concerned thus far with general questions about rocks and their

TABLE II
COMMON MINERALS OF THE IGNEOUS ROCKS

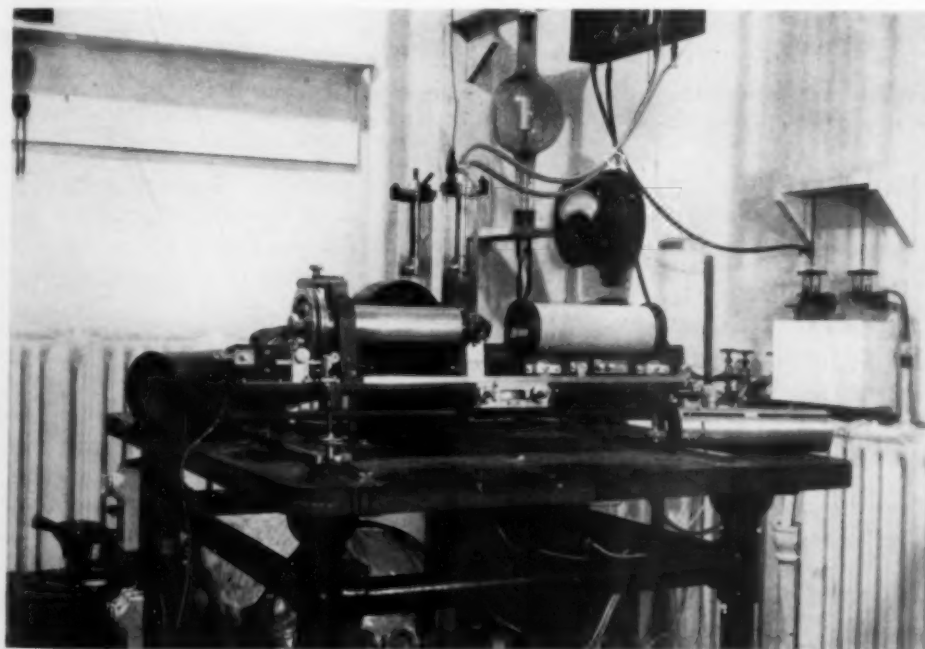
Minerals	Principal components
Olivines	Mg_2SiO_4 and Fe_2SiO_4
Pyroxenes	$CaSiO_3$, $MgSiO_3$ and $FeSiO_3$
Amphiboles and micas	Complex Fe, Mg and Ca silicates
Feldspars:	
Lime feldspar	$CaAl_2Si_2O_8$
Soda feldspar	$NaAlSi_3O_8$
Potash feldspar	$KAlSi_3O_8$
Quartz	SiO_2

sources, particularly the igneous rocks and their mineral constituents; let us now consider more specific problems bearing on the origin of these materials. When a magma crystallizes to form an igneous rock or rocks, at what temperature does this crystallization process begin? Does crystallization begin at the same temperature in two magmas of different chemical composition? Do all minerals separate simultaneously? If not, what is their order of crystallization? Does a magma of a particular chemical composition always yield the same rock or rocks? If

not, what chemical and physical processes operate to yield the different rocks?

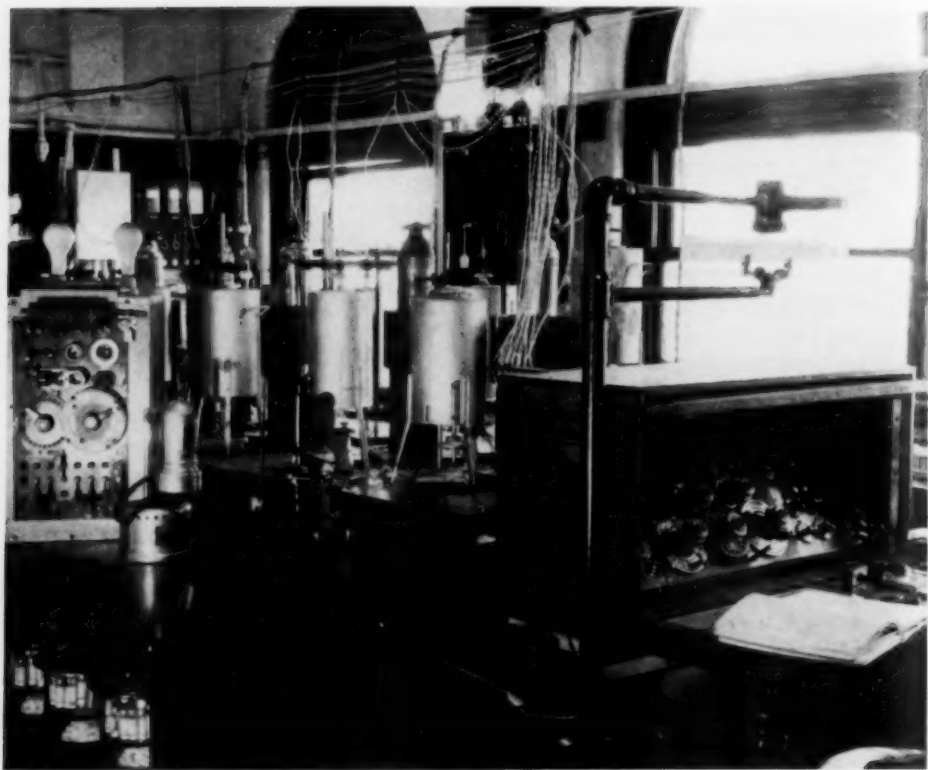
Many questions arise concerning the individual minerals found in the igneous rocks. Do minerals always have constant chemical compositions? If not, what factors influence the composition of certain minerals? What is the origin of zoned crystals (crystals whose optical properties under the microscope indicate concentric zones of different but related chemical composition)? Why do certain minerals in the igneous rocks appear corroded as if they had crystallized and subsequently were partly dissolved? Why do certain minerals show reaction rims (mineral grains with surrounding rims of different minerals)?

These inquiries are but a few examples of the problems that engage the attention of the scientists who are devoting their efforts to investigating the nature and origin of the physical materials of the earth. We shall attempt to show how



(Photo by C. J. Ksanda.)

FIG. 3. X-RAY GONIOMETER USED TO STUDY CRYSTAL STRUCTURE AT THE GEOPHYSICAL LABORATORY.



(Photo by J. Harper Snapp.)

FIG. 4. A HIGH-TEMPERATURE INSTALLATION AT THE GEOPHYSICAL LABORATORY, SHOWING FURNACES, THERMOCOUPLES, POTENTIOMETER, TEMPERATURE REGULATORS, AND MICROSCOPE USED IN STUDYING MELTING RELATIONS OF SILICATES.

these problems have been attacked and what progress has been made toward a better understanding of the origin of the igneous rocks and their minerals.

COOPERATIVE LABORATORY STUDIES

Field geologists, by examining igneous rocks in various parts of the world and their relations to one another and to the surrounding rocks, have accumulated a large amount of observational information. Petrographers, by studying these same rocks in detail in thin sections under the microscope, have obtained a large number of facts concerning the more minute structures and the relationships of the several minerals to one another. Analytical chemists have supplied infor-

mation about the chemical compositions of the rocks and of their mineral components. These various kinds of information about igneous rocks raise questions concerning the nature of the processes by which they have been formed that point the way to laboratory experiments for determining the fundamental behavior of silicate solutions of the ten chemical oxides that make up 99 per cent. of igneous rocks.

Although we are considering the chemistry of only ten chemical substances, the problem is very complex, for there is an almost unlimited number of possible combinations of these ten materials. If we are to have success we must break up the problem into smaller units and solve the rela-

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tions of the ten substances to one another by isolating the variables and investigating them individually.

An experimental study, in the laboratory, of silicate solutions comparable to the rock magmas at high temperatures and pressures requires the combined efforts of various experts. High temperatures and pressures must be produced by some means and accurately measured and controlled. Careful work of an entirely different kind is necessary to produce and control the chemical compositions of the artificial rocks. The petrographic microscope is essential in order to identify the artificial minerals that are produced and to follow their changes in chemical composition. The use of x-rays is important in order to identify very finely crystalline phases and to elucidate the laws of crystal structure, polymorphic forms (two or more crystal forms of the same chemical substance) and solid solutions (continuous variation or variation within definite limits of the chemical composition of a single crystalline substance). A photograph of the x-ray goniometer used for this purpose is given in Fig. 3. Delicate physical methods are required for measuring the heat changes that occur when an ounce or a ton of a mineral melts or crystallizes.

In the Geophysical Laboratory of the Carnegie Institution of Washington, such a group of geologists, petrologists, physical chemists and physicists has been collaborating for more than thirty years. Over a thousand articles describing these investigations have appeared in scientific journals. The program, under the directorship first of A. L. Day and later of L. H. Adams, has been carefully planned and executed. By proceeding from the simple to the complex and solving variables one by one, very substantial progress has been made toward the solution of the problem of rock formation as a whole. The experimental investigation of rocks is a conspicuous example of progress in a difficult field through cooperative effort.

Here, I shall confine my remarks to the studies of silicate melts at high temperatures, my particular field of interest, without in the least minimizing the importance of pressure. This important factor has been already considered in detail by my colleagues L. H. Adams¹ and R. E. Gibson.²

ROCK-FORMING SILICATES AT HIGH TEMPERATURES

Before proceeding with a study of a complex solution of ten different rock-forming oxides we required some knowledge of the effect of temperature on the behavior of the separate substances. Silica (SiO_2), the most abundant of these oxides, occurs naturally in four different crystalline forms whose relations to one another with respect to range of stability were not known and had to be determined. The melting point of SiO_2 was known to be fairly high (considerably above the melting point of iron), but no exact value had been determined. One of the first problems to be solved was the production and accurate measurement of high temperatures up to the melting point of platinum (1755°C). After the establishment (by A. L. Day and others) of an absolute temperature scale for high temperatures by means of the nitrogen thermometer, measurements of the exact melting points of certain silicates were possible.

In place of natural rocks and minerals, artificial ones were prepared from pure chemicals by a series of meltings in electric furnaces. With these simple synthetic mixtures, a careful control of chemical composition was possible. A natural specimen of even a simple mineral like quartz (SiO_2) usually contains small amounts of other minerals as microscopic inclusions which can not be conveniently separated and which often serve merely to confuse the investigator. Since the

¹ L. H. Adams, *SCI. MONTHLY*, 44: 199-209, 1937.

² R. E. Gibson, *SCI. MONTHLY*, 46: 103-119, 1938.

fundamental behavior of a substance is primarily due to its chemical composition, artificial rocks or minerals made from pure chemicals are to be preferred to natural materials, which contain small amounts of undesirable impurities.

Early studies of the melting relations of minerals were made by means of heating or cooling curves, a method very successfully applied by the metallurgist in his study of metal alloys. Most silicates, because of their low heat conductivity and their slow rate of chemical reaction, gave either no results or relatively poor ones by this method. With the development of the method of quenching it became possible to obtain accurate and reliable data on the melting relations of many of the rock-forming silicates.

METHOD OF QUENCHING

In the method of quenching, a particular mixture of pure chemicals is placed in a platinum crucible, platinum being used because it is inert chemically and has a high melting point (1755°C.). This mixture is heated above its melting point several times, with intermediate crushing and powdering, until it is very uniform in composition. When removed from the hot furnace, it is cooled quickly by plunging it into cold water. Most silicates, when so treated, have the property of "freezing" to a glass, which is merely a supercooled liquid that has not crystallized. After this glass has been powdered it is examined under the petrographic microscope in liquids of known indices of refraction. When it is absolutely homogeneous, that is, uniform in chemical composition, all glass grains have exactly the same index of refraction. A portion of this uniform material is crystallized by maintaining it at a suitable temperature until crystals form, which may be a period, depending on the chemical composition, ranging from five minutes to five years. The crystals are identified by means of their optical prop-

erties in polarized light under the petrographic microscope. With silicates it is usually advantageous to have crystals (small in size so they may come to equilibrium with the liquid rapidly) present, because of the sluggishness of chemical reactions in silicate-melts and their tendency to supercool.

We are now ready to determine what happens to this particular composition at any selected temperature. A small sample of the crystallized glass is placed in a tiny platinum envelope. By using a small amount we avoid difficulties of different temperatures within the charge. The envelope is hung next to the junction of a platinum-platinum 90 per cent., rhodium 10 per cent. thermocouple which is placed at the "hot point" or center of the zone of uniform temperature in a platinum-wound electric furnace. In order to read the temperature we use a potentiometer and thermocouple, a combination which is merely an electrical thermometer. The temperature is controlled and kept constant within 2°C. by means of a special electrical thermostat developed by physicists at the Geophysical Laboratory. The charge is suspended by means of a fine wire across two heavy platinum wires. When the chemical reaction has gone to completion and holding for a longer time produces no further change, the equilibrium is "frozen" by dropping the tiny platinum envelope into cold mercury. This is accomplished by melting the supporting wire with a heavy electric current. Cooling is so rapid during quenching that there is no time for chemical change to take place, and a "frozen" sample of the material is obtained. Any liquid that was present at the temperature of the experiment will be glass, and any crystals that were present in the liquid may be identified by their optical properties under the microscope. By a series of such quenching experiments on a particular composition, the beginning

of melting, completion of melting and temperature of formation or disappearance of any particular kind of crystals—in other words, any phase change—may be determined. By selecting a series of related chemical compositions, preparing such compositions and making the necessary quenching experiments, much systematic and valuable information may be obtained concerning the complicated processes of crystallization.

In summary, the investigation of melting phenomena in silicate-melts consists of holding a small sample in a furnace at a fixed temperature, which is measured by means of a thermocouple and potentiometer and controlled to $\pm 2^\circ$ with an electrical thermostat. After adequate time has been given for chemical reactions to proceed to completion at the fixed temperature, the equilibrium mixture is "frozen" by very rapid cooling. The nature of the sample at the temperature of the experiment is determined by a microscopic examination of the quenched charge. Fig. 4 is a photograph, taken in the Geophysical Laboratory, which shows these necessary pieces of equipment for determining melting relations in silicates.

PHASE EQUILIBRIUM DIAGRAMS

Phase diagrams are graphs used to express the facts of equilibrium in heterogeneous systems—systems involving equilibrium between two or more phases. What do we mean by the words phase, equilibrium and silicate system?

A chemical system is said to be homogeneous when all parts of the material under consideration possess the same chemical and physical properties. It is said to be heterogeneous when it is composed of two or more homogeneous parts separated by physical and sometimes chemical discontinuities. The homogeneous parts of a heterogeneous system are called phases. For example, at its freezing point liquid water is in equilibrium with solid ice and water vapor. There are three phases present: one

liquid phase, one solid phase and one gaseous (vapor) phase in the one-component system, water (H_2O).

The concept of phases is readily understood, but somewhat greater difficulty is usually experienced when we come to consider what is meant by the term component. The components of a system are not synonymous with the chemical elements or compounds present (constituents of the system), although either or both may be components. By the components of a system we mean only those constituents whose concentration can undergo *independent* variation in the several phases. In the system previously chosen as an example of phases, the number of constituents taking part in the equilibrium is only one, the chemical substance water (H_2O). Hydrogen and oxygen, the constituents of water, are not components because they are not present as such but are combined chemically in definite proportions as H_2O , and their amounts, therefore, can not be varied independently. As components of a system the smallest number of independently variable constituents are chosen. Equilibrium is not dependent upon the actual amounts of the phases, but only on the fact of their coexistence.

The underlying law of equilibrium in heterogeneous systems is the phase rule developed mathematically from thermodynamic principles by the great American scientist J. Willard Gibbs during the last half of the nineteenth century. Its use in its present form is due to H. W. Bakhuis Roozeboom, the Dutch chemist, who at the suggestion of van der Waals applied Gibbs's phase rule to a study of actual chemical systems and used it as a guiding principle in predicting the conditions at equilibrium. This rule for a system in equilibrium may be very concisely summarized in the form of the equation:

$$P + F = C + 2 \text{ or } F = C + 2 - P,$$

where P is the number of phases in the system at equilibrium, F is the number

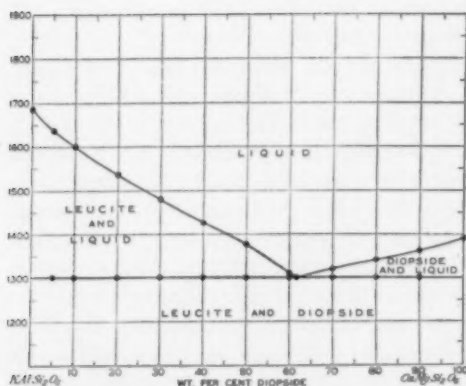


FIG. 5. EQUILIBRIUM DIAGRAM FOR THE SYSTEM, LEUCITE—DIOPSIDE. (BOWEN AND SCHAIERER.)

of degrees of freedom (the variability), and C is the number of components. The number of degrees of freedom is the number of the variable factors (temperature, pressure and concentration of the components), which must be fixed in order that the condition of the system shall be completely defined. It should be noted, however, that the phase rule tells us the condition of the system *when equilibrium is reached*, but does not tell us anything

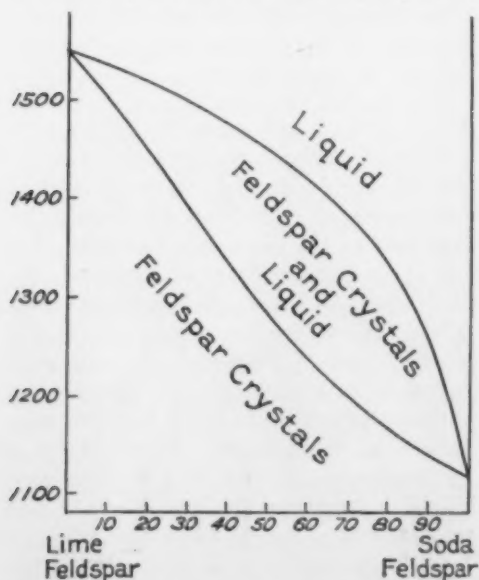


FIG. 6. THE SYSTEM, LIME FELDSPAR—SODA FELDSPAR (PLAGIOCLASE FELDSPARS). (BOWEN.)

about the rate of attainment of equilibrium. For the system, water, at its freezing point, already used as an example, we have one component and three phases, and we find, by substituting these values in the equation, that $F=0$. In other words, the coexistence of these three phases in the system, water, is possible only at a fixed temperature and fixed pressure; that is, the system is invariant. If we raise the temperature the ice melts and we lose the solid phase, ice. If we lower the temperature the water freezes to ice and we lose the liquid phase, water.

BINARY SYSTEMS

First, let us examine the simpler melting relations found in two-component (binary) systems of rock-forming substances. As type I, we shall select a mineral pair, leucite—diopside, showing the simple eutectic relation (that is, no solid solution). A binary phase equilibrium diagram for this system is given as Fig. 5. We notice that temperature is plotted in the vertical direction and composition in weight per cent. in the horizontal. The actual compositions, on which measurements were made, are designated by solid circles. Each component has a congruent melting point; that is, the solid melts sharply, at a definite temperature, to a liquid of the same chemical composition as the crystalline solid. We notice that pure leucite has a high melting point, 1686°C. , and that, as we add diopside to leucite, the temperature of completion of melting (liquidus curve of leucite) is lowered; and similarly as we add leucite to diopside (liquidus curve of diopside), the temperature of completion of melting is lowered. The point at which the two liquidus curves intersect is the eutectic point, and its temperature (1300°) is called the eutectic temperature. All compositions in the system, except the pure components themselves, become completely solid on cooling only at the eutectic temperature, and either leucite or diopside sepa-

rates first, depending on which side of the eutectic the selected composition lies, and is joined by the second solid phase and becomes completely crystalline at the eutectic temperature. Conversely, on heating, the first liquid appears at this eutectic temperature in all compositions except the pure components. The only two solid phases in the system are *pure* crystals of leucite and *pure* crystals of diopside. The eutectic temperature is lower than the melting point of either pure component.

As type II, we shall select a mineral pair that show a complete series of solid solutions. We shall use the well-known plagioclase feldspars, so common in many igneous rocks, as an example. The diagram for anorthite (lime feldspar)—albite (soda feldspar) is given as Fig. 6. The liquidus curve, we may observe, looks quite different from the eutectic type (type I). By the addition of albite to anorthite the temperature of completion of melting (liquidus) is continuously lowered; or conversely, by the addition of anorthite to albite its liquidus is continuously raised. We see, also, that there is no single temperature comparable to the eutectic temperature of type I (the one temperature at which *all* mixtures begin to melt on heating or become completely solid on cooling), but that each mixture begins to melt at a different temperature (solidus curve, lower curve in Fig. 6).

This type of diagram is most interesting to the student of igneous rocks, because so many of our rock-forming minerals are solid solutions, either of this simple type or of much more complex types. The olivines, pyroxenes, amphiboles and feldspars are outstanding examples. From this type of diagram, we may see why zoned crystals are found in rocks. Let us examine the crystallization of a typical mixture.

We shall follow the crystallization process of a mixture of the composition 50 per cent. lime feldspar 50 per cent.

soda feldspar, assuming that cooling is slow enough so that equilibrium is reached, at all times, during the crystallization process. This composition is represented by the point *x* (Fig. 7), which is at a high temperature and completely liquid. On cooling, the first crystal appears at 1450° (temperature of point *a*) and its composition is represented by the point *b*, a composition much richer in the lime feldspar component than is the composition of our chosen mixture. On further cooling, there is a simultaneous change in amounts and in

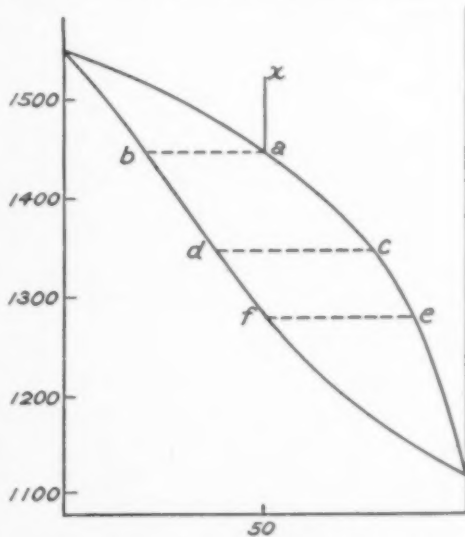


FIG. 7. CRYSTALLIZATION PATHS IN THE SYSTEM, LIME FELDSPAR—SODA FELDSPAR.

chemical composition of *both* the crystals and the liquid. When the temperature of the flat *dc* is reached, the crystals have moved in composition from *b* to *d* (have become progressively richer in soda feldspar) and the liquid has moved in composition from *a* to *c*, but there is much less liquid present. When the temperature has reached 1287° (temperature of point *f*), the mixture becomes completely solid, and the crystals, which have moved in composition from *d* to *f*, have the composition 50 per cent. lime feldspar 50 per cent. soda feldspar, the same composition

as x , our chosen mixture. The last bit of liquid had the composition e . Because of the continuous reaction between both crystals and liquid during crystallization, this is called a continuous reaction series. Our chosen mixture crystallized to yield crystals of the same composition, but note what an involved course the path of crystallization followed.

In the crystallization of a magma to form igneous rocks, cooling is often too rapid to allow equilibrium to be reached, and the first crystals to appear are not afforded sufficient time to react with the liquid. Thus they become coated with a

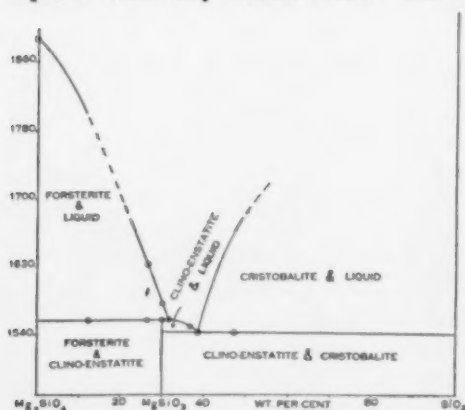


FIG. 8. THE SYSTEM, FORSTERITE—SILICA, SHOWING THE INCONGRUENT MELTING POINT OF MgSiO_3 . (BOWEN AND ANDERSEN.)

more sodic (or less calcic) feldspar zone which effectively removes the inner zone from contact with liquid. In this failure to react with liquid, we have a rational explanation of zoning in plagioclases. Sometimes reversal of zoning is found that indicates an abrupt change in conditions during crystallization. We can not attempt to go into all the possibilities, but wish merely to indicate how processes of mineral growth can be explained when we apply the information to be read from such phase diagrams.

We have reason to believe that in the crystallization of magmas, fractional crystallization is very important in yielding the great diversity of rock types. Since

the crystals of feldspar continuously react with the liquid present, if they are removed by floating or sinking in the liquid or are effectively removed—at least in part—by zoning, the whole course of crystallization is changed and the composition of the residual liquid moves to the right (Fig. 7). With a great amount of fractionation, the residual liquid will approach pure soda feldspar in composition. No natural magma is so simple as this feldspar diagram, but similar principles apply in the many more complicated diagrams which more nearly approach rock compositions.

Another type of binary diagram, which involves reaction between crystals and liquid, is chosen as type III. In Fig. 8 we have the system, forsterite (Mg_2SiO_4)—silica (SiO_2), with the compound clinoenstatite (MgSiO_3), which has an incongruent melting point. Certain complications at the high silica side of the diagram have been deliberately omitted. When crystals of MgSiO_3 are heated, melting begins at 1557°C . with a separation of crystals of Mg_2SiO_4 (incongruent melting). The material becomes completely liquid only at 1577°C . Conversely, on cooling, forsterite crystals separate at this latter temperature and continue to separate until the temperature of incongruent melting (1557°C) is reached. At this constant temperature they react completely with the liquid of composition (MgSiO_3 97.5 per cent., SiO_2 2.5 per cent.) to form MgSiO_3 . At perfect equilibrium, the crystals of Mg_2SiO_4 and the liquid are exhausted simultaneously, and only MgSiO_3 crystals remain. Thus we see that the liquid of composition, MgSiO_3 , with perfect equilibrium, follows an involved path of crystallization, but yields only crystals of MgSiO_3 . We note, however, that forsterite (Mg_2SiO_4) crystallized first, and at a lower temperature reacted with liquid to yield clinoenstatite (MgSiO_3). Such a pair of minerals is called a reaction pair.

When cooling is too rapid, complete reaction between crystals and liquid at the reaction point fails to take place quantitatively, the course of crystallization is changed, and we may have crystals of forsterite, clinoenstatite and silica in the final product. In this reaction process we note the nature of the origin of reaction rims of pyroxene (clinoenstatite) around grains of olivine (forsterite) in rocks.

MORE COMPLEX SYSTEMS

In the foregoing discussions only three of the simpler but important types of binary systems have been considered. No reference has been made to partial or limited solid solutions, to components with several different crystalline modifications and to many others. Although many ternary, or three-component, systems have been thoroughly investigated, no quaternary, or four-component, system of silicates has as yet been completely studied.

We shall include here a diagram (Fig. 9) of the ternary system, $\text{CaO}-\text{FeO}-\text{SiO}_2$, without complete explanatory details. An equilateral triangle is used to express chemical composition in terms of three components. If we expressed temperature vertically from this triangular base, we should have a triangular prism. To retain a plane figure, we indicate these temperatures by contours of temperature called isotherms. A diagram of the system, $\text{CaO}-\text{FeO}-\text{SiO}_2$, without isotherms, is given here to show how fields of stability of minerals are delineated. Additional diagrams, showing isotherms, paths of crystallization and three-phase boundaries, are necessary for a more complete presentation of the laboratory data.

To represent a quaternary system, we use a tetrahedron whose faces are equilateral triangles. For convenience, we often show, as a plane figure, the tetrahedron with its faces laid down on the plane of its base. Such a diagram is given

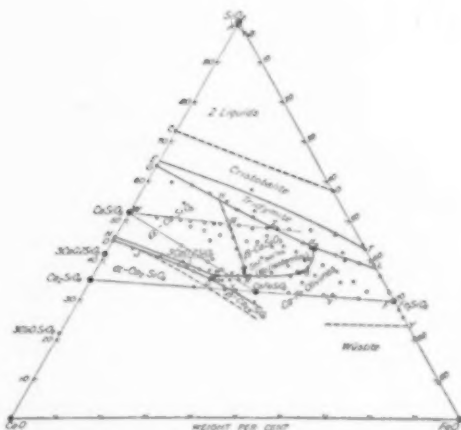


FIG. 9. THE SYSTEM, $\text{CaO}-\text{FeO}-\text{SiO}_2$, WITHOUT ISOTHERMS, SHOWING FIELDS OF STABILITY OF MINERALS. (BOWEN, SCHAIRER, AND POSNJAK.)

in Fig. 10, which represents in skeleton form three different quaternary systems that are now being studied to ascertain the nature of residual liquids from fractional crystallization in compositions which approach those of certain rock magmas.

COMPLEX MINERAL GROUPS

Earlier, we asked many questions about the nature and variations of the individual minerals found in igneous rocks.

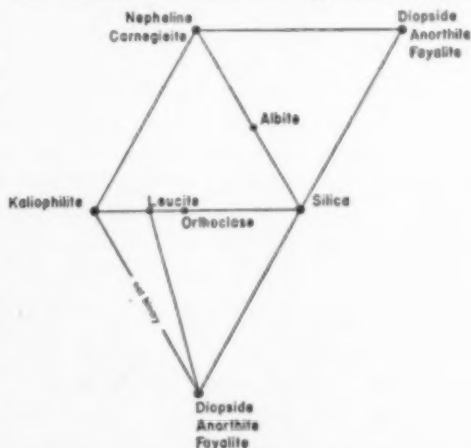


FIG. 10. QUATERNARY DIAGRAMS SHOWING IN TERRELATIONS OF SYSTEMS INVOLVING BOTH EARLY- AND LATE-CRYSTALLIZING MINERALS OF IGNEOUS ROCKS.

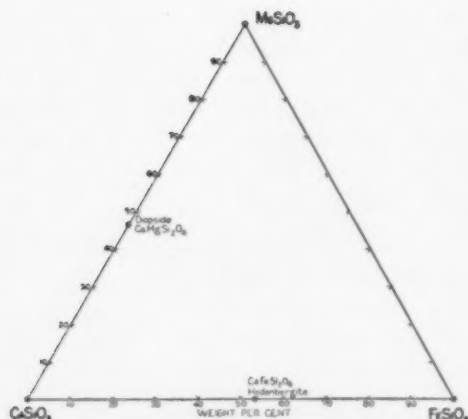


FIG. 11. THE COMPOSITION TRIANGLE, CaSiO_3 — MgSiO_3 — FeSiO_3 (NOT TERNARY), SHOWING THE MOST IMPORTANT MOLECULES OF THE ROCK-FORMING PYROXENES.

Here, we shall select one of the most important groups of rock-forming minerals, the pyroxene group, in which N. L. Bowen and I have had a particular interest. The pyroxenes present exceptional complexity both of crystalline modifications and of chemical composition. They are a series of polycrystalline solid solutions, some of the molecules of which are completely miscible and others only partly so. The important mineral molecules which enter into the composition of the rock-forming pyroxenes are given in Table III. The three most important molecules are the metasilicate molecules

TABLE III

MOLECULES OF THE ROCK-FORMING PYROXENES	
CaSiO_3	Wollastonite, pseudowollastonite
MgSiO_3	Enstatite, clinoenstatite
$\text{CaSiO}_3 \cdot \text{MgSiO}_3$	Diopside
FeSiO_3	Ferrosillite, clinoferrosillite
$\text{CaSiO}_3 \cdot \text{FeSiO}_3$	Hedenbergite
MnSiO_3	Rhodonite, bustamite
$\text{CaSiO}_3 \cdot \text{MnSiO}_3$	Johannsenite
Molecules containing	
Al_2O_3	Augites
Fe_2O_3	Augites and bairingtonite
TiO_2	Titaniferous augites
$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$	Jadeite
$\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$	Acmite, negrite

CaSiO_3 , MgSiO_3 , and FeSiO_3 . The compositions of these are indicated in Fig. 11.

Laboratory data for the sides of the triangle are already complete. The relations between diopside and MgSiO_3 are given in the ternary system, diopside—ferrosillite—silica. CaSiO_3 and diopside form a binary system in which there is a limited amount of the diopside molecule in solid solution in the low-temperature form of CaSiO_3 (wollastonite). Data for CaSiO_3 — FeSiO_3 and MgSiO_3 — FeSiO_3 have been published in the ternary systems, CaO — FeO — SiO_2 , and MgO — FeO — SiO_2 , respectively. The incongruent nature of the melting of acmite has been determined and complete data are given in the system, Na_2SiO_3 — Fe_2O_3 — SiO_2 . Studies are now in progress, or are planned for further determination of the exact composition-temperature-stability relations in this important rock-forming mineral group.

CONCLUDING REMARKS

In this place, we could hope to indicate only the general character of the processes operating in nature to produce the great diversity of igneous rocks. From the foregoing presentation, we may realize that, although the broader problem of the chemistry of igneous rocks concerns only ten rock-forming chemical substances, it is, indeed, an involved but very fascinating one. We have seen that orderly physical and chemical principles govern the processes, and that it is possible, by dividing the problem into many interrelated simpler problems, to study the actual temperatures and processes of rock formation in the laboratory, and to use certain minerals as geological thermometers. Each mineral system that is studied yields information concerning certain processes of rock formation, but usually raises many new problems that await further experiments for their solution. Science continually seeks new truths or a better understanding of the old ones.

ARE WE ALONE IN THE UNIVERSE?

By Dr. R. S. UNDERWOOD

PROFESSOR OF MATHEMATICS, TEXAS TECHNOLOGICAL COLLEGE

WHEN most people looked upon our earth as a unique flat surface stretching all the way out to the base of the sky-bowl and resting on bed-rock, which reached, presumably, all the way down, man's position was a delightfully happy one. The limited size and well-stocked condition of creation satisfied his gregarious instinct and gave him a comforting sense of all-pervading companionship; while his obvious preeminence among created things left absolutely nothing for his vanity to crave. Those, indeed, must have been the days!

But always in human affairs there has to be some prying intellectual to spoil the perfect bliss of ignorance. Some one, sooner or later, was bound to knock out the foundation which supported earth and sky, leaving only a round ball suspended lonesomely in space, and a rolled-away curtain where once had been the friendly gate of heaven. Bleak emptiness was beyond, except for scattered flaming beacons like the sun, a pinch, here and there, of debris, and a few insignificant earth-cousins all but lost in the void. No wonder that thoughtful persons scanned those tiny balls with wistful eyes, looking for signs of activity which would remove that new sense of cosmic loneliness and give mankind companionship, at least, in place of his lost focal position in the scheme of things. No wonder that enlightened religious leaders longed for scientific assurance that the great universe was not pricked in one spot only by a tiny stir called life—a stir so infinitesimal in the stupendous setting of blind mass and force that it could be nothing more than a chemical accident. Even yet life might take on meaning and dignity if only it could

match the boundlessness of space with an all-pervading quality of its own.

But help came only slowly from the scientists. There was a time, not so long ago, when top-rank astronomers apparently considered it beneath their dignity to discuss the question of life on other worlds. The gradual turn of the tide is probably due chiefly to the growing conviction that this is a genuine research problem and not just a subject for unverifiable guesses. And this particular development is certainly of much more importance than the latest conclusion about the atmosphere of Mars in respect to its fitness for human beings. For it means that the possibility is at last recognized that earth-bound creatures may be able eventually to know with certainty that there is or is not life on Mars, that there is or is not life on Venus, and even, perhaps, that life exists or does not exist on the remote satellites of other suns and other galaxies. It means, further, that scientists investigating any of a thousand problems in astronomy, physics, chemistry and other fields will keep always on the watch for data bearing on a very live question, realizing more and more how numerous and diverse are the odd bits of knowledge or theory which may prove now or later to be significant.

Already the accumulated direct and indirect evidence would require many books for a reasonably complete discussion. An article such as this, then, can do no more than point out a few of the main considerations and lines of evidence.

Logically, perhaps, we should first ask what is meant by "life." Any attempt at a definition, however, gets us into philosophical and biological niceties which only obscure the point at issue, since most of

us believe that we could recognize the phenomenon in almost any of its probable forms. After all, we find upon introspection that we are emotionally concerned not so much with other-world life as with consciousness, and particularly with the higher form of the latter called "intelligence." But since on earth life-quickened matter and the cruder organisms merely set the stage for the climactic appearance of mind and thought, there will be for many people a keen interest in the search for mere extra-terrestrial life in any form whatever.

One other matter of a general nature remains to be discussed before we consider specific sites of possible life. It has been remarked that earth-life derives from two chief facts: first, the instability of carbon compounds within the temperature range found on our planet; and second, the presence of water as a medium of solution. These dual prerequisites have allowed a tremendous variety and range of living forms, from bacteria to whales in size, from equator to pole and from ocean depth to mountain top in place, and from seconds to centuries in individual life spans. And yet they have at the same time indicated a possible limit in the conditions which our kind of life can endure without the artificial aids of intelligence: a forbidding zone of perpetual cold like that approached in the Antarctic wastes, of drouth such as Death Valley holds, and of heat like that in the geysers of Yellowstone Park. Beyond these limits, it is true, something totally different might emerge in the mysterious ways of creation—such forms, for instance, as could live in a world of blazing heat by virtue of silicon life cells fed by molten iron bloodstreams. But perhaps the greatest single lesson of astronomy is that of the essential unity of observed creation. One set of chemical elements apparently suffices for the earth, the sun and all the known galaxies of space; and one great law of gravitation holds every

celestial body in its place. It seems reasonable, then, to look first of all for *our* kind of life on the other planets, and to assert for the purposes of clarity that such strange creatures as may be stirring in the places beyond the pale of earth-living conditions are not examples of what we are pleased to define as life. This gives us a dogmatic basis upon which to exclude the overwhelming bulk of matter in the universe, including our own sun and all others, and probably, though not certainly, nebulous and meteoric material, planets too near to or too far from their primary suns, and planets too small to hold an atmosphere.

What remains? Well, in our own solar system, in addition to the surely inhabited earth, there are several prospects worth examining in detail, while outside this system the sky is literally the limit. Suppose we consider first of all our two immediate planetary neighbors.

Coming often within fifty million miles of the earth, and occasionally venturing within astronomical speaking distance only thirty-five million miles from collision, the planet Mars naturally rates a good deal of attention from mere neighborly curiosity on our part. But when, on the seasons of near approach, we peek out through our telescopic windows and find that the shades are up invitingly; that a well-marked face, peering at us in the revealing sunshine, gives more than one hint of strange goings on; and that we have before us almost, but not quite, enough detail to settle some vexing questions immediately, is it any wonder that our scientific interest is spurred to the point of extra-special investigation, and that one man at least has made this puzzle a life-study? Here, unquestionably, is one of the most promising sites of life in the none-too-select astronomical neighborhood of the belligerent earth-beings.

Most of the significant features of Mars have been described so often in popular literature that they will be pointed out

only briefly in this broader survey. First we should note the remarkable similarity to the earth in the two astronomical features of a twenty-four-and-a-half hour day and a season-making axial tilt which is practically identical with that of our planet. The important distinctive features are the planet's smaller size and consequent lighter atmosphere, and its greater distance from the sun, by about one half. This last feature means, of course, that less light, heat and energy are received per unit of surface. Then there are the white polar caps, suggesting snow, fog or hoar frost, which appear rather suddenly in the Martian winter, dwindle away at ragged edges in the spring, and sometimes disappear entirely in the summer. There are the seasonal darkening stages of the permanent markings which suggest the growth and ripening of vegetation, and which are indeed hard to explain under any other hypothesis. And finally there are the controversial canals, seen as geometrical lines by some and as ill-defined streaks by others, but existing at least in the form of broad channels which have appeared in photographs. The crux of the argument about the canals lies in the fact that the patient observer can undoubtedly view more details through the telescope, in the fleeting moments of good seeing, than can be photographed by a process which averages good and bad conditions. Eventually, perhaps, a lucky photographic shot aided by an improved technique allowing shorter exposures may yield a clear-cut picture which will settle the issue. But in the meantime it seems fair to state that the majority opinion of astronomers has tended more and more to the conclusion that the odds are in favor of some kind of plant life on Mars. But on earth animals eat plants, and plants live on carbon dioxide existing primordially in the free state or exhaled by animals. Perhaps there are parallel conditions on Mars. It is true that no trace of carbon dioxide

has as yet been found in the Martian atmosphere. On the other hand, the spectroscope appears to reveal a trace of oxygen, and much more seems to have been tied up in the oxidation of the red Martian surface, like our Painted Desert sands. Since in the theory of planetary gases oxygen is believed to appear in the free form only as it is liberated by plants, this trace of the element is another link in the chain of evidence which makes the still incomplete case for the thesis of life on Mars.

Next on the list of probable life-harbors is the planet Venus, our celestial neighbor on the sunward side. Less than twenty-five million miles from the earth when closest, and considerably larger than Mars in addition, it would be the obvious candidate for the most intensive study if it did not, logically enough but none the less annoyingly, always turn its dark side toward us on these near approaches. A second disconcerting attribute is a heavy blanketing atmosphere which so effectively hides the surface that no earth-man knows how often it turns around. And that apparently minor point has a highly important bearing on the question of its habitability. For if one side always faces the body it circles, as is apparently the case with Mercury and all minor satellites, that face must be unbearably hot, the other side must be dark and frigid, and the borders must be blasted by endless hurricanes. As a matter of fact, a rotation period equal to about thirty of our days is indicated by some meager lines of evidence. Even in the extreme case of a day equal to the year, the chances for life on Venus would not be hopeless; but in view of an uncertainty about a vital matter which is probably only temporary, it seems best not to allow this prospect any more of our crowded space.

Mercury, nearest known planet to the sun, has little or no atmosphere, and also has the almost fatal habit of keeping one

face toward the celestial furnace. Jupiter and Saturn, huge and distant planets blanketed by heavy atmospheres which seem to be composed largely of ammonia and methane gas, are likewise poor prospects as life-bearers, while their satellites and the outer planets are even less promising. One would certainly be rash to deny dogmatically that life exists on any or all of these places; but it seems safe to state that the *present* odds are against the existence of our particular kind of life.

What about the moon? A generation ago a schoolboy would have recited the conditions thus, with glibness and finality: "The moon is a pock-marked satellite of the earth, deceased long ago if she ever lived, and now totally without water, atmosphere or life."

Has the verdict changed? Only in the not insignificant respect that the proper phrase is now "no appreciable atmosphere." Certainly it would be highly surprising if the moon were proved to be totally airless, since the nearby earth receives daily millions of meteorites containing each its quota of gas. There is no inconsistency in the probable consequence of this fact and the very clear proofs that our satellite is practically without air. The question is merely a matter of degree—of how much contraband gas the moon might smuggle past our delicate detecting instruments. In the May, 1938, issue of *Popular Astronomy* appears this statement: "As far as actual observational evidence goes, it appears that values of λ less than two times ten to the minus four have not been excluded," which means in plain English that the surface of the moon could, for all we know to the contrary, have an atmosphere about five thousand times more rare than our sea-level air. This conclusion assumes more importance in connection with repeated observations in one lunar crater, and, to a lesser degree, in others, of daily changes ascribed *possibly* to some low form of moss-like growth.

A related observation will give some hint of how widely ramifying are the clues in this great investigation. It is to the effect that there are surprisingly few indications on the moon of current changes due to meteoric bombardment, and that no light-flares from impacting meteors have ever been observed on the darkened surface at the new or quarter phase. Coupling this development, which is theoretically improbable on the assumption of a totally airless moon, with the observed fact that most earth-encountering meteors are consumed by friction at a height at which our own planet's atmosphere is extremely thin, we arrive at the startling conclusion that maybe after all the moon gets a little atmospheric protection from pelting rocks. At least we see that the question of barrenness or life is not an entirely closed subject, even in the case of this nearby rocky outpost.

And now finally, when we come to the endless possibilities for life outside the solar system, it may be thought that here at least is a field in which we can never hope to bring investigation to the aid of our hopeful surmises. But again this is not the case. For one line of attack appears immediately. How likely and how frequent, among the uncounted Milky Ways of space, is the kind of rare accident or common celestial occurrence which called the earth and its sister planets into being? This, of course, depends upon our explanation of the origin of the solar system. And, fortunately, so mathematically precise must be the final theory in order to account for things as we find them, that it can scarcely be false when once it is entirely satisfactory. Already one feature of the final plan has emerged clearly and almost unmistakably to give us encouragement—that of a plane determined by a point and a line, the point being the sun and the line the path of a passing star.

But the comparative frequency or rareness of a habitable planet like our earth

depends also upon many other factors which are in the pathway of present investigations. It depends upon the star density, past and present, of our galaxy and the millions of others known; upon the number and distribution of space derelicts—dead suns which might pass living ones and leave planetary systems in their wake; upon the nature of a star's life history, with the working clues of variable, binary and exploding or "new" stars. It depends upon the currently debated existence of living spores within the messengers of space—the free-coursing meteorites—which may even now be carrying the seeds of life from dying worlds to new and fertile fields. It depends, in fact, upon the whole astronomical picture now unfolding before us, and, less directly but no less certainly, upon the entire interlocking field of science.

The question, you will note, centers upon the probable number of planetary systems per million or billion of suns rather than upon the likelihood that our particular system has no near-counterpart in space. Most astronomers to-day are inclined to think that a planetary family is a comparatively rare phenomenon in space; but probably no one would make the statement stronger than that. Certainly the whole burden of proof would rest upon the rash theorist who would make our solar system unique in

the universe. To get an idea of the probabilities involved one has only to recall that by a very conservative estimate there are, in the galaxies within range of present telescopes, not less than one hundred million billion suns. Enough suns so that, if they were reduced individually to the size of buckshot, they would fill a line of trucks strung end to end from Boston to San Francisco and folding back on itself about two hundred times. One would be a trifle brash to claim special status for the buckshot he loves best in this caravan! And when one of the chief laws we see in operation about us is that of repetition, the chance that we are not alone in the universe seems to border as close upon certainty as anything we know that has not been proved.

Thus the stage is set, and the little planet Mars is seen to have been given undue significance. It seems to have life, but if this is a mistake, it doesn't much matter after all. The important thing, astronomically speaking, is that here is a sun with at least one inhabited satellite—our earth. If Mars is as dead as the proverbial doornail, we can still look outward with confidence that blind chemical forces have not cast us up as living accidents on the huge dead banks of eternity. Somewhere in space are many, many fellow-travelers on the brief but hopeful trek of life.

ANIMAL EXPERIMENTATION

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IN beginning my discussion of animal experimentation, I wish to give initial emphasis to the second word of our theme, not the first. For experimentation, being primarily a method of discovery, has not only been making extraordinary contributions to our knowledge and culture at a constantly increasing rate, but possesses certain properties of great interest quite apart from the materials the experimenter may select as most suitable for his problem. Experimentation with animals has the same general objective as experimentation with plants and with materials supplied by inorganic nature. The materials are of secondary importance. The problem is the focus of interest.

If there is one thing more than another that characterizes us all, it is, I suggest, our common immersion in a sea of problems. Some of them spring up out of immediately practical individual needs—for food and clothing and protection from the elements, from disease and from each other. Some of them belong especially to family life, awakening questions on reproduction and sex and development and heredity and the educational process. Some pertain directly to the larger life of the community and nation, to crime and corporate behavior and the exchange of the stupidities of war for the enlightenments of peace. And others carry us willingly to the frontiers of knowledge with only understanding and appreciation as our goal.

Whatever our problems, and however near or far, we solve them adequately only with adequate techniques. In early childhood, these were miraculously simple. It was enough to lay our questions on our mother's knee or some other altar

similarly consecrated by our gifts of faith. An authoritative word was our sufficient solution, as in the days before the dawn of science, when supplication usurped investigation's place.

As a matter of history, science did indeed show itself clearly above the naive intellectual horizon characteristic of childhood only when processes began seriously to awaken the same sort of compelling interest as the results to which they led. For the immediate and familiar needs of every day, man had been accustomed from time immemorial to use his common sense. Confronted with less familiar issues, remote from his pressing creature wants and transcending his rule-of-thumb techniques, he had long been content to comfort his ignorance with supernaturalism. The time came, however, when reflective minds perceived that the gods they had created were no less fallible than themselves. There followed the conviction that intellectual security was to be found for practical men in the causal mechanisms of events rather than in the events themselves.

Though this conviction was expressed in highly speculative forms, it was basic to scientific progress. Six centuries before Christ the imaginations of a Thales and an Anaximander sketched the broad outlines of a universe that was for the first time self-contained and mechanically conceived, capable of investigation from within, independent of interference from without. Henceforth, scientific knowledge was to accumulate in direct proportion to the development of adequate techniques of observation.

Foremost among these is what we commonly call the scientific method. Typically, it begins with a *question*, which

receives a tentative answer, the *hypothesis*, that is then put to a test in the form of a critical investigation of the problem thus defined. It is, *par excellence*, a method of discovery, giving to observation both motive and direction. But discovery may lag. Outstanding among accelerating devices is the experiment, which attains its full importance in the investigation of mechanisms and processes. For the present discussion it may be characterized briefly as observation under conditions that are chosen, arranged and controlled by the observer himself. Experimentation is thus a serious and aggressive intellectual procedure suggesting neither the passive receptiveness of a photographic film nor the wanton curiosity of one who kicks a dog to see what it will do.

By way of illustration, let me recall the story of an experiment with animals that was not only a model of simplicity and method but historically significant as well. It began with Homer. In the nineteenth chapter of the *Iliad*, he put into the mouth of Achilles, mourning over the body of Patroclus, a fear lest flies enter the latter's wounds and breed worms therein. Five centuries later, this common fact of Homer's day had apparently escaped the attention of Aristotle, who accounted for maggots in decaying flesh by a spontaneous, or, as Harvey used to say, equivocal generation. Backed by Aristotle's enormous prestige, this view persisted unquestioned by the bookish few through the dark vicissitudes of the next two thousand years before being put to an objective test.

The seventeenth century had arrived, with the microscope and the barometer and the thermometer and the air pump and other devices that promoted quantitative observation and stimulated accurate inquiry. Galileo had been born and driven into retirement by ecclesiastical authority. Not, however, before he had made his classical experiments on falling

bodies. A product of his influence, the *Accademia del cimento* had been organized, dedicated to the promotion of experimentation. Into this new company of explorers, the Tuscan physician Francesco Redi was admitted. He knew the *Iliad* and the biological books of Aristotle. He knew also the practice of the butchers of his day, who believed that their wares could be kept free of worms by excluding flies with coverings of cloth. "But," he said in a noteworthy sentence from his "Experiments on the Generation of Insects" (1668), "belief would be vain without the confirmation of experiment, hence in the middle of July I put a snake, some fish, some eels of the Arno, and a slice of milk-fed veal in four large wide-mouthed flasks; having well closed and sealed them, I then filled the same number of flasks in the same way, leaving them open." In so doing, Redi provided what we now recognize as an essential in every well-conducted experiment—its *control*. He goes on: "It was not long before the meat and the fish in these second vessels became wormy and flies were seen entering and leaving at will; but in the closed flasks I did not see a worm, though many days had passed since the dead flesh had been put in them." Subsequently, Redi improved his technique by using a cover of Naples veiling that permitted air to enter but excluded flies as before. In this case he had set up an experiment in which the covered jar differed from its control in one essential only. It was an *experimentum crucis*, the technical ideal of every experimenter. The results were as before. So it appeared that the butchers, following the ancient Bard, had been right, and the philosopher, leaping with closed eyes to a conclusion, wrong.

But the possibility of spontaneous generation had not been eliminated; especially of those minute organisms first revealed by the lenses of Redi's contemporary Leeuwenhoek. New experi-

ments were forced by criticism to new refinements of technique that in turn provoked new subtleties of criticism. By mid-nineteenth century they had come to the ears of the young chemist Pasteur, whose later extraordinarily beneficent researches on and for animals and man need no further reference here. His experiments as a bacteriologist extended to the limits of microscopic vision the conclusions reached by Redi for maggots.

But further exploration opened up a world of still more minute existences. Ultramicroscopic bacteriophages and viruses, being invisible, were recognized by what they did. Many of them have now been measured with quite reasonable accuracy by methods not requiring them to be seen. It is still recent news that the virus concerned with the propagation of the tobacco mosaic disease has been isolated in crystalline form, a prelude to the investigation of its composition and chemical structure. Such discoveries have added further impetus to the exploration of the borderland between the living and non-living world already being approached from several other directions. Far more immediate interest, however, is being shown in the mechanisms underlying vital activities, than in the possible event of spontaneous generation itself. Let us leave Redi's problem, then, at this point, to consider a modern experiment differing from his in motive and material, involving a very simple operative procedure, and selected especially for its striking simplicity in general.

Recall if you will the microscopic "bell-animalcule" *Vorticella*, its sub-conical body set like a narrow wine glass on an excessively slender stem, and its free edge bordered by hairlike cilia whose rapid beating creates vortices in the water drop that is its universe. Always a fascinating object to the microscopist, it is especially (I had almost said doubly) so when in process of division.

This was as a youngster in my labora-

tory had discovered it, one lunch hour, when I found him sharing his attention between sandwich and microscope. He had made an admirable series of line drawings in which one could almost see the fission plane pass gradually from the ciliated mouth of the "bell" toward the stalk. There were now two sub-conical bodies not yet fully separated and superficially very much alike. On one of them, however, there was a second set of cilia, near the apex of the bell, which were entirely absent in the other. Furthermore, the latter was now in full possession of the stalk. The fission plane had passed a little to one side of it, leaving the individual with the new ring of cilia hanging to the other by a tenuous protoplasmic strand. Here, then, was the situation: the individual with the new ring of cilia lacked a stalk, while the individual with the stalk lacked the new cilia.

What was the explanation of this difference? It looked as though the stalk somehow prevented the appearance of the cilia that became visible only in its absence. Adopting this as a preliminary guess or hypothesis—how was it to be tested? One obvious method was to amputate the stalk of a normal individual. This led, however, to certain technical delays. Needles must be sharpened to a fine cutting edge; and the operator must develop skill sufficient to use them in a water drop under a reversing microscope that made a needle actually entering from the right appear to be entering from the left. He must also be able to put the cutting edge down precisely where the stalk joins the body, notwithstanding complications introduced by the usually spasmodic contractions of the stalk itself when touched.

All these obstacles were finally surmounted. The delicate operation was performed at last with complete success, and the vorticella swam directly away from its stalk, bell mouth foremost. It was on that aspect of the body that it

came to rest after several minutes, the apex of the bell from which the stalk had been cut pointing most fortunately right up into the microscope. Fifteen more minutes passed. Then, unmistakably, the beginnings of the expected cilia were suggested as a ring of barely visible dots. These became as we watched them delicate hairlike processes, that as they lengthened began to wave slowly and rather uncertainly, then faster and faster until, full grown and beating in a unified rhythm with great rapidity, they bore the stalkless body up into the drop, apical (i.e., stalk) end now in advance.

It was clear that cilia could develop in the absence of the stalk. But would they persist if the stalk should reappear? The answer to this question came when the swimming body finally touched and stuck to the substratum just where the stalk had been cut off. For at that point a new stalk began to grow out under our eyes. As it lengthened, carrying the bell up with it, the cilia completely disappeared by absorption.

The operative experiment in miniature had now reached its immediate objective, not, however, without stimulating other questions concerning the mechanism controlling this extraordinary alternation of specific structures. These brought it at once into the company of a mass of experimental data on interdependence of parts and dynamic equilibria in living systems that had already accumulated from many sources, especially from the simple plastic organisms of which we have been contemplating an extreme case.

There is not time to go into this vastly interesting field of experimentation. It can only be said that these studies have now progressed in some cases to such a point that chemical substances are being recognized as important factors in the processes of development and differentiation. Though we still know little more of the cilia-stalk relation in *Vorticella*

than the fact itself; and though it still remains an absorbing mystery how the cut end of a flatworm becomes reorganized into a new head; it is probable that such mechanisms involve chemical factors just as they unquestionably do in certain other cases. The so-called organizer of Spemann, for instance, is but one of a group of substances whose presence in the amphibian embryo at the right times and places has been shown to provide the necessary conditions for a normal development. What Claude Bernard first called internal secretions, now commonly associated with the activities of the ductless glands of the higher animals, including man, are actually produced to some extent by every active cell in the body. Since the discovery of *secretin*, we have had an intelligible mechanical explanation for the remarkable way in which the pancreas pours its characteristic digestive juices into the intestine just as food ready for digestion is passing through. Even the characteristic activation of muscles by nerves has recently been shown to be produced by such well-known substances as adrenalin and acetylcholine secreted at their motor terminals. A small army of investigators is showing, similarly, that characteristic sex phenomena involving both form and function in men and women are dependent on internal secretions whose composition in some cases is now well known. Though it is not within the limitations of this paper to describe them more specifically at this time, it is desirable to suggest that the chemical correlations that are being successfully studied in such highly complex organisms as man exist also in some appropriate form in every organism however minute and simple and in every cell.

Other aspects of the general problem are being outlined by students of genetics who are attempting to define more clearly the conditions under which the genes (constituting the physical basis of

heredity) are characteristically active. This is done in the first place by transferring given tissues—such, for instance, as a patch of skin from a fowl or the rudiment of an eye from a *Drosophila* larva—from their normal setting to animals of similar type but different genetic constitution, where they must develop under conditions not entirely similar to those from which they were removed. Even the behavior of single genes has been observed in connection with eye color in *Drosophila*, a subtlety of approach to the traditional issue between heredity and environment that has already yielded positive results and is being pursued, as all fundamental physiological problems must be ultimately, with the cooperation of chemists. Since genes are known to react with their near neighbors occupying places on the same chromosome, such studies promise to throw much needed light on some of the most fundamental mechanisms of protoplasmic organization.

From such general considerations, I will now ask you to turn with me to an investigation of a very special type that came under my observation a few weeks ago in a New York hospital. Its *motive* was initially practical; the *method* was quantitative, calling for a large number of carefully controlled measurements of physiological processes by means of elaborate and finely adjusted apparatus over a long period of time; the *material* consisted of a series of human infants prematurely born.

You are aware that the life expectancy at birth in this country has increased to its present value of about sixty years largely through a corresponding decrease in infant mortality. In 1935, the infant death rate within one year of birth was less than half what it was in 1915, thus reflecting the progress of knowledge and improved infant care. During the same two decades, however, the death rate within one month of birth had doubled;

and the record showed that approximately sixty-five per cent. of the fatal cases had been born prematurely. Such figures revealed a public problem of very large dimensions. They also suggested the strategy of investigations now under way, in which the requirements of *premature* infants occupy places of peculiar importance.

In the hospital to which I refer, a suite of rooms has been isolated and furnished for studies of infant metabolism. In the midst of its admirable equipment—the fruit of many years of experience and criticism—one could not help thinking of the great pioneer Lavoisier, whose quantitative studies with balance and calorimeter led him to a true conception of the rôle of oxygen in the rusting of metals, the burning of inflammable substances and its relation to the subtler combustions continually going on within the body itself. His measurements of the respiratory exchange of gases in man at work and rest were the first of the kind and laid the foundation for modern respiration calorimetry, a familiar clinical application of which for the determination of the basal metabolic rate is now a commonplace of medical practice.

In the present case, the calorimeter was a small oblong metal box in which an infant under observation could be placed, comfortably clothed and resting on a little mattress so shaped that all excretions might be conveniently collected *in toto* for subsequent investigation. There was a glass window in the air-tight cover. An ample measured supply of air, after passing through a series of bottles that removed all its moisture and carbon dioxide, entered at a constant rate by a single opening. Within the chamber, which was kept at a constant temperature, this air picked up moisture again from the lungs and skin of the infant, the desired humidity being maintained by regulating its rate of flow. On leaving the chamber, it passed through an-

other set of drying bottles, and in addition, small samples of air were withdrawn by a very ingenious automatic device at regular intervals and pooled for quantitative analysis.

Without going farther into details, I hope this sketch of the apparatus has made clear its design, namely, the most accurate possible measurements, under the most carefully controlled conditions, of everything taken from the air by the infant during the period of observation and everything eliminated, whether solid, liquid or gaseous. From such measurements of a long series of infants, significant typical changes in their metabolism have been correlated with changes in their age. And progress has been made in two obvious directions; first, in a more effective control over the hazards to which premature infants are subjected; second, in fuller understanding of the physiological mechanisms fundamental to the development of man and of organisms in general. This intimate relation between the results that can be used at once and those for which no occasion has yet been recognized deserves more consideration than we can give it now. Instead, you will be glad to hear that the babies cooperating in this experiment in human biology have returned to their mothers invariably benefitted physically—and by all the usual signs emotionally also—by these brief episodes of service to compatriots not yet born. Though they slept unconscious of it all, their mothers knew what they were doing, were always willing and often very proud. As a result of many investigations along similar lines, by many observers, premature babies no longer die for lack of air-conditioned nurseries in well-equipped hospitals of the present day.

Another experiment on human material came to my attention that same evening when we saw "Yellow Jack," a screen version of the famous expedition of Walter Reed and his colleagues to

Cuba that established on a sound experimental foundation the agency of a mosquito (*Stegomyia*) in the dissemination of yellow fever and the first great step toward its control. I shall not recount this now familiar and very honorable story. What you have seen or may see on the screen is entirely authentic as to all essential details. For the experiments, an organism was needed that was itself susceptible to the fever. Man alone at that time was known to meet that requirement. So five enlisted men volunteered for this hazardous service, as men have always volunteered when the hazard and the need were great. Would you have had them do otherwise? To-day, we know that mice are adequate and far more convenient material for experiments still in progress. World-wide exploration for the sources of the disease have made it unfortunately clear that the magnificent intention of the Rockefeller Foundation to destroy it completely can not be fulfilled. But man can now be immunized against it. And the method now in use, by which several hundreds of thousands of individuals have been protected, was developed, all Californians will be interested in recalling, by a former secretary of their State Board of Health, now director of the International Health Division of the Rockefeller Foundation, Dr. Wilbur A. Sawyer.

Though not one of the five volunteers lost his life in the original experiment in Cuba, you are aware that one of the staff of investigators, Lazear, died; and that three other distinguished investigators have since been sacrificed. Dr. Sawyer recovered from an infection obtained in the course of his investigations. Courage of this sort has been a commonplace among physicians ever since Thucydides, describing the plague of Athens, testified as an eye witness that "physicians died themselves most thickly, as they visited the sick most often." It took courage of the same order for Reed to issue his call

for volunteers. Grateful relief is expressed in these words of his written to his wife when the result of the experiment was clear.

... It has been permitted to me and my assistants to lift the impenetrable veil that has surrounded the causation of this most wonderful, dreadful pest of humanity and to put it on a rational and scientific basis . . . The prayer that has been mine for 20 years, that I might be permitted to do something to alleviate human suffering, has been granted.

During my first days in a physiological laboratory, I made the acquaintance of a dog who had long been a cheerful source of gastric juice delivered as needed through a gastric fistula established by operation five years before. He was amiable, had a habit of chasing his tail until he became too stout for that exercise, and held an honorable place in our regard as a contributing member of the scientific staff.

Twenty-five years later, a younger relative met a group of dogs at Johns Hopkins School of Medicine that had been trained to assist in an investigation then under way. Each of them, as his turn came, would jump up on the oper-

ating table, lie down—wagging his tail perhaps—and without being restrained in the slightest, would permit the operator to plunge a hollow needle through the chest wall into the heart so as to withdraw blood directly from that organ. This was a routine procedure, many times repeated! The dogs gave the same evidence of pride in performance as dogs do that retrieve game or entertain their master's friends with tricks. Similarly, you will recall, dogs helped Pavlov and his co-workers through many routine experiments in their studies of the physiology of the learning process that brought new objective and quantitative methods of wide applicability to psychology and a new term—the conditioned reflex—into our language.

Such contributions to the advancement of knowledge give experimental animals a place of peculiar importance in human affairs. The death that frequently overtakes them does not lessen it. On the contrary, death acquires from this permanent service a certain dignity that mere extermination as a community problem in the public lethal chamber can not ever confer.

UNDERSTANDING HUMAN GESTURES

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GESTURES as a species of human behavior have been sadly neglected. The greatest of psychologists, Wundt and Freud, have not exactly neglected them, but have done little more than mention them. Most psychologists completely disregard them. Until recently no one tried to study them experimentally, and even now there are more problems connected with them than any psychologist could hope to solve in a lifetime.

Every layman knows that people gesture, since gestures are commonly employed in social intercourse. Every one is familiar with the fact that some individuals perform nervous movements or possess so-called mannerisms. There are, however, gestures hardly noticeable to the untrained eye, for which no appropriate name was known until recently, and which differ from the rest. How then can we distinguish the various types of gestures from each other? When and why does each type occur? If their meaning is clear when they are used in communication, what do they mean when not so used?

Boards of trade use gestures in buying and selling grain for future delivery. With the fingers held vertically brokers indicate quantity. Each finger is used to represent five thousand bushels, and as many as twenty-five thousand bushels may be represented by four fingers and the thumb. Movement toward the trader means buying; movement away, selling. For prices there is another code. One finger extended means one eighth of a cent, and so on to five eighths. When the four fingers are extended, but pressed close together, three quarters is indicated. The clenched hand with the thumb alone

extended means seven eighths of a cent, while the thumb between the index and the middle finger is the signal for a split quotation.

Scouts have a language of their own. Throwing both hands up means "Nothing to fear!" Holding an open hand aloft, and moving the arm from right to left and from left to right, a few times, means to scouts, "Attention!" Thrusting the arm forward means "Stop!" with both policemen and military men. Swinging the hand from the shoulder across the body to the other side, in a horizontal direction, means, in military language, "Go this way!"

Gestural expression was common among North American Indians. They had thousands of signs to convey meaning without sound, but other peoples have also used gestures for this purpose. The natives of Timbuctoo place two fingers astride a finger of the other hand to indicate riding. Similarly, when they press a heavy head against an open hand, they mean "Go to sleep." Closing the fist with the thumb between the index and middle fingers indicates derision among certain Europeans. Turning the back and lifting the skirt is a sign of disrespect among the French and others. Throwing the head back and making a chucking noise with the tongue signifies negation among Turks. Massaging the abdomen to show satisfaction was common among Indians, and is still imitated by our youngsters. The Ainu of Japan lightly tap the nose or the mouth to express surprise, while the Negro Bantus of Africa move their hands before the mouth, when surprised, and Australian aborigines protrude their lips as if to whistle.

Ceremonials in various groups have relied on gesture for communication of meaning and thought. Indeed, this type of communication had served the purpose of social control before government by law or canon began to serve that purpose. For instance, the ceremonial involving the expression of affection requires, with us, embracing and kissing on the mouth or cheek; but when our civilization was still in its beginning stages, smelling heads was a sign of affection among Mongols; rubbing noses among the Maori and the Esquimaux; pressing mouths and noses upon the cheek and inhaling the breath, among the Burmese; and smelling heartily of each other while juxtaposing noses, among the natives of Samoa. The informal controls represented by these and similar procedures can hardly be matched by those social techniques which, though historically nearer to us, are often less effective.

Gestures, however, have been used for purposes of formal control in both primitive and ancient society. Witness the civilities used to propitiate, in ceremonial, important personages, kings and gods. Undressing to signify surrender had been a custom among Syrians; and to this day in Samoa the natives quickly strip themselves to their girdles as a sign of surrender. The Batokas throw themselves on the back, roll from side to side, and slap their thighs while doing so, to say: "You need not subdue me; I am subdued." Turks extend the right arm, move it down to the level of their heads, while stooping, and lower it again, to signify: "I place this earth upon my head as a sign of submission to you." Joining hands overhead, and bowing, is an ancient sign of obeisance among the Chinese. Stretching one's hands toward a person, and striking them together at even address, is used by the Congo natives to convey the impression of humility. The Dahomans crawl and shuffle forward, walking on all fours; the Fundah and

Unyanyembans put their palms together for the other person to clasp as gently or severely as he wishes—all to express obedience, humility and the reality of social control.

The origin of these symbolic movements, varying with different peoples, is not always easy to find, in spite of the fact that they seem clear and simple to the members of the groups in which they are practiced. In many cases there exists no logical relation between the gestures and their meaning. This is true of our own as well as of the primitive gestures listed. Thus for example, crossing fingers to ward off evil, among our own people, may appear simple enough, but actually we are at a loss to explain how or why such a sign was put into use. And why do we shake the index finger when some one has displeased us? Why do we beckon to some one to call him over, as in the familiar "Hey, waiter!"? Why do we clench our fist when we are angry? Why do we wave the hand sideways to indicate negation?

J. F. Dashiell has traced these conventional gestures to meaningful acts which were gradually reduced to a few simple movements for convenience in communication. Thus crossing fingers is probably the easiest way to symbolize a cross, and for that reason has been used to challenge the authority of the dark and evil powers. Shaking a finger at some one, likewise, originated from the act of shaking up offenders who had placed others in an angry mood. Clenching the fist is probably an abbreviation of the act of striking. Beckoning to some one is a remnant of the act of pulling people by force. Waving the hand sideways can be traced to the act of pushing others bodily aside. All these gestures are thus conveniences which are understood only because they had been fully expressed at one time. They are not merely conveniences, but genuine signs of social progress, for they take the place of acts which, in their

more extended forms, represent control through force.

These conventional gestures do not appear strange, because they are so common. Other types of gestures, much less common, do appear to be strange. We all know individuals whose personalities have been stamped with certain types of movements euphemistically called mannerisms. These individuals twitch their shoulders, twist their faces, rhythmically close one or both of their eyes, and show similar types of behavior, irrelevant to both time and place, in response to a habitual form of impulsion which they can not inhibit. These gestures are technically known as *tics convulsifs* or, simply, tics.

Some time ago W. C. Olson, of Michigan, made a study of the tics of school children. He watched the children in front of the classroom, and by the aid of a seating plan, a watch and a pencil kept careful record of all movements, such as putting fingers in the mouth, picking the nose, pulling the ear, fingering the hair, etc. Only one type of movement was observed at a time, but every child who displayed the movement within five minutes was noted.

Olson found that children behaved in very much the same way day in and day out, in spite of the fact that the observations were as much as a week apart. Even a year later, his records showed, some of these habits persisted. Olson discovered that children reproduce each other's gestures in certain parts of the classroom, thus spreading their nervous habits; but he did not claim that imitation was the only cause of their appearance. Even more frequently the cause is to be found in persistent irritation and emotional shock.

Psychiatrists have been interested in the causes of tics for many years, and they have reported success in treating individuals afflicted with them. An eminent psychiatrist of Baltimore recently

described to me the case of a patient suffering from an uncontrollable shoulder-twitch. In the course of treatment it was found that the patient had been frightened by a robber who had come up from behind. Soon after this associated piece of evidence was brought out, the twitch disappeared. By more or less protracted methods other tics have been removed. Normal people also manifest movements which seem to be without cause. These movements I have called *autistic* (or self-directed) gestures. Thus, if we yawn when we are not in need of sleep; if we wet our lips when these are not dry; when we clear our throats though no cold or obstruction seems to bother us; when we suddenly get an urge to snap matches within our reach; or when we smooth our hair smooth enough to satisfy the most meticulous, do we mean to *say* anything?

Gestures of this type, because they appear to be directed to no one outside, can not be mistaken for the two types of gestures previously mentioned. They are not, like conventional gestures, intended to convey, by an established technique, some obvious meaning. They are not, like tics, habitual in nature, taking place again and again, regardless of time or circumstance, and without relevancy to the behavior of other people. Are they merely chance phenomena, "automatic" movements, occurring without special cause?

Behavior goes on all the time. From the point of view of the observer certain acts may seem detached, but as a matter of fact there are no empty intervals of thought, no incidental acts, in living organisms. There can be no irrelevant behavior from the point of view of the actor himself at least. This is true, whether or not he can verbally or subvocally account for the logic of his acts. What makes these gestures difficult to understand is not, then, their "automatic" nature. First, it is the absence

of prepositions and conjunctions which might facilitate their translation into language symbols. Second, though they may resemble words, they are explicit acts which are constantly interrupted by implicit acts such as thoughts, and other explicit acts, such as speech, with which they are continuous.

Alexander Luria has pointed out that "irrelevant" gestures which appear together with other kinds of reactions are "motor storms," and that they indicate the presence of mental conflict. In any conflict an individual is prepared to act in two or more ways, but always (unless disorganized) acts in one way only. Acts that are not carried out are repressed. Repressed acts become emotional attitudes or "complexes." These autistic gestures are traceable to complexes which are thus drained off, in spite of the solution which the conflict had received.

In a series of carefully controlled experiments begun in 1931, the writer has shown that autistic gestures, in spite of their obscurity, constitute a legitimate and possible field of psychological investigation. He has demonstrated that gestures can be studied reliably and that they recur in a given individual under similar conditions. He has proved that autistic movements have an emotional background and that they have a genetic history not unrelated to the origin and goals of movement in the living organism generally. He has found that these gestures bear a definite relation to personality types. At present, by means of a somewhat intricate experimental setup, he is attempting to prove that a certain group of gestures has similar meanings in various individuals. These experiments proceed on the assumption that, first, there is always a cue in the situation which is associated with the gestures, and second, that the symbolism expressed in the gesture can be understood if we know something of the nature of the conflict which the individual experiences at the time he gestures.

There are undoubtedly *general* meanings conveyed by these autistic gestures in individuals having conflicts which are similar enough to permit of their interpretation as a group. Some gestures, for example, imply a suppressed attitude of resistance. These gestures may be expected in individuals who can not demonstrate their hostile attitudes toward a social situation or some individual. Inhibiting these attitudes, they present the picture of unconscious resistance, nevertheless. As an illustration we might take clearing the throat. A certain professional man, though a church member, is in a state of conflict with regard to the place of religion in his life. On one occasion, while lecturing, he says: "We do not think of medical terms as final (pause) or sacred," clearing his throat. It may be observed that the word "sacred" occurring with the phrase "medical terms," had reinstated and immediately evoked a state of secret opposition. This is typical of autistic gestures. The word which sets off the gesture may have no relation to the other words in the sentence, so far as the individual is concerned. Hence, the total meaning of the sentence is destroyed, while a part of it, in the light of the individual's past experience, acquires special meaning.

There are autistic gestures which seem to suggest that the individual evades the present situation, reminiscent of his conflict, by symbolically shutting himself out of it. Recently a large daily carried an interview with a state's attorney under fire for favoritism to gangsters. The interview began with the following description:

Mr. S. was tired.

He hoisted his feet to the top of the work-table, pushed his spectacles up on his forehead, passed a large smoothing gesture over the lines of care in his massive countenance, and looked at his questioner with one of those searching looks which give you an uncomfortable feeling that the gazer is looking through you at some person behind you.

Here we find the dominating gesture—

passing the hand over the face—to be essentially an escape, or at least an evasion, type of movement, in which the actor shuts himself out of the picture without actually leaving it.

Finally, we might name a type of gesture in which the individual, unable to escape the situation and unable to meet it in any other way, recedes to an early pleasure-giving stage in which all things were possible. Thus he can tolerate a situation which might otherwise prove intolerable. A man who had sought the chairmanship of a college department, but was unable to secure it, squats down in the chairman's seat (as if to say: I *eliminate* it), resorting to one of the earliest pleasure-giving postures which human individuals acquire. The body truly *speaks*. This man could express his conflict over the place which he had been eager to have not only without words, but without admitting his cravings to any one, including himself.

These are but a few illustrations of gestural interpretation. It will be observed that the specific reference of a gesture, even when so interpreted, is still left to be determined. If there is resistance on the part of an individual at a certain point in conversation, why is it there? If the individual escapes from an unpleasant situation, why does he do so? These are matters which only a scrupulous analysis of an individual's background can reveal, with his own aid.

There are other difficulties. In the study of gestures, as in the study of all human behavior, we find individual differences occupying an important place. We said previously that these unconscious movements might be similarly interpreted only to the extent to which we could equate or generalize upon human conflicts. But some individuals manifest persistent gesture patterns which do not appear with similar frequency in other individuals, showing that, at least quantitatively, there is a difference. Personality types, as determined by early de-

velopment, possess modes of expression which differ from those of other personalities having conflicts of virtually similar general design. Thus we see that the study of autistic gestures involves all the difficulties found in the study of human behavior generally and, besides, special difficulties due to their subtlety and unconscious nature.

An opera-singer once asked the writer to teach him the meanings of gestures, so that he, the rogue, could understand the gestures which he believed certain fair ladies were directing at him. Of course, this request was merely a projection of his wish that fair ladies might make secret representations to him; but, in any case, the writer had to beg off, for he realized that, under the conditions, many a lady might be accused of having motives of which she was not only unaware, but which she did not even have.

A coed once told a college instructor that if he did not stop twisting, stroking and pulling a key suspended from his watch-chain, she would probably lose her balance. In this case the instructor's gestures, in spite of their unwitting nature, obviously belonged in a system of interstimulation and response. The young lady, at least vaguely, was aware that she was responding to the gestures, though neither she nor the instructor knew why *she* had responded to them as she had, why *he* had performed the gestures of which he was guilty, or what those gestures had meant. Is a conversation of autistic gestures, then, an impossibility? The answer to the question depends on the extent to which we may expect others to interpret the autistic gestures that we make.

A moderate amount of training may enable a person to recognize the subtlest types of movement, in so far as direction is concerned. Lip-reading, with and without touch, has been found to be feasible. Again and again "mind-readers," or muscle-readers, have demon-

strated that it is possible, by placing hands on the head of some person who is informed as to the location of an object, and who is instructed to "think hard of where it is," to be guided to it by muscle movement. Similarly, it has been found possible to select a certain card in a deck, tell a number of which the subject is thinking, locate a word in a volume or trace a pin in a room.

The case of Clever Hans is too well known to need much description. The claims which had made the animal famous were properly modified when it was revealed that the horse could solve an algebraic problem even when the problem was written out in another room. The prerequisites seemed to be that some one present know the nature of the problem. When this was discovered, the head-movements of bystanders were recorded on a kymograph. In spite of their minuteness, jerks ranging from one fifth of a millimeter upward could be detected by the horse without an intervening medium. The perception of subtle cues is now an established fact.

Barring cases of muscle-reading based on prearranged schemes, we may say that those other instances in which the detection of minimal cues has been found to be a reality, can be explained on the grounds of variation of touch and tremor, in cases where contact is provided. Some expert "mind-readers," of course, may not resort to touch at all. They depend more on auditory cues, such as nasal whispering, footsteps or changes in the subject's respiration. Where visual cues are used, changes of posture, movements of eyes and lips and various mimetic cues are resorted to. In some cases the heat radiations of the subject's body have been found to be a source of guidance.

In order to respond to a cue, however, one must be familiar not only with the direction of the cue, but with the implications of the cue in his own behavior. The obtuseness of cats directed to an object by an outstretched arm or by the fixed gaze of their master is familiar to all who have dealt with cats. Neither will human individuals always respond to cues in their environment. The embarrassment of people who are given signs which have not been prearranged and whose meanings they do not understand, because they get no warmth of recognition from them, is well known to all. What is true of language, of artistic paintings, of collective representations of unfamiliar groups is also true of gestures. In an ultimate sense we do not know what symbols signify, unless we know what conflicts originally forced their inhibition and symbolic existence.

Theoretically, autistic gestures occur because they give us temporary relief from tension and conflict. To gesture means to think frankly along certain lines, and to *express* our thoughts with impunity. By means of self-directed gestures we can say things about ourselves which we are loath to regard as attempts at personal advertising. We can, furthermore, say things about others, in their very presence, which we are loath to admit as possible. The fact that we can act without admitting even to ourselves that what we do has meaning is precisely the reason that other people's gestures are beyond our comprehension. We understand the conventional gestures of others, because our own conventional gestures are clear to us. If we could understand our own autistic gestures, we might understand the autistic gestures of other people.

SOME CRITICISMS OF COLLEGE EDUCATION

By Professor SUMNER B. ELY

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IN the last year or two several articles have appeared, mostly in our leading popular magazines, finding fault with our college education. Most of them have taken the ground that the college or university was not accomplishing what it should; that men of true culture were not being produced; and that the training given was narrow and not in keeping with the present advance of ideas and ideals generally.

On the whole, the articles seem to be destructive rather than constructive. Certainly the reverence for things past is to-day much less than it was a few years ago; and there is nothing particularly new or startling in the idea that we must discard what has been built up through years of effort and evolved by the human race by long and arduous experience. At present in Europe all the rights and privileges we used to think belonged to nations and peoples have been forgotten; and it seems, too, as if every principle of economics was abandoned for new untried ideas or for discarded old ones brought forward again as something original.

All we have to do is listen to some of the present-day music to appreciate what has happened to the established rules of harmony, counterpoint and form. No tonality, no vestige of a pure chord, violent and amazing rhythms. It may be a sign and symbol of the times that much of our music has become mechanistic and cubical, without significance of form. In the past as musical thought developed, we have had to modify our conception of what music should be, to give scope enough to allow a composer to completely express himself; which he might be unable to do in a more restricted form

and medium. However, a slow development is one thing; but the sudden abandonment of all that has gone before is quite another thing. Our extremists in music to-day have discarded every rule and thrown away all that has been developed in the past, and started anew from the beginning. Such a procedure is not only a tremendous waste of the labor and work which we have inherited, but it is an actual loss of civilization.

What is civilization but a mass of data, knowledge and traditions left to us, which, instead of discarding, we should use and try to improve upon? Why do we admire one work of art more than another? Because we have been educated to certain standards, left by the great artists of the past, and we compare new works with these old standards. We may not know that we are doing so, the process of comparison may be entirely unconscious; but if it were not for these standards, we should simply be uncivilized.

Of course, standards may change or be wrong. The psychologist speaks of "fixed ideas." Take, for example, the enormous debt which has been put on this country in the last few years. For a time everybody was talking about it, and we deplored and condemned it because everybody else did; but now we begin to take for granted that it must be; at least we hear little or nothing said about it. We accept it because everybody else accepts it. However, because some of our standards may be thoughtlessly accepted, it does not follow that we do not have standards or could do without them.

The above is merely given as an illustration of what has occurred in one department of art. Many other examples

could be quoted, for our whole philosophy of life seems to have become unsettled and confused. Perhaps this is an aftermath of the terrible suffering the world war caused; and which by pushing us back towards a barbarian stage has brought out again those primitive instincts and passions that are still deep down in us all. Whatever the cause, there is a great tendency everywhere to abandon all conservatism and for our liberals and radicals to become anarchists. Is it any wonder, then, that the field of education has come in for its share of criticism?

There is no doubt that institutions of learning become rigid or crystallized. They have, through long years of experience, found that certain methods and procedures in teaching are good; and naturally they hold to these standards which they have set up and in which they have confidence. An individual or small group of individuals can easily change ideas or view-points; but our established colleges do tend to get into an inflexible mold, so that any considerable change must come about very slowly. And gradual changes in educational matters are taking place. For example, of late years our technical and engineering colleges have introduced more and more general or so-called "cultural" studies among the strictly technical ones. We also find the idea growing that civilization is likely to go to pieces unless man can be motivated by reason instead of by emotion. If it were possible to replace our politicians of to-day by men who had a scientific attitude of mind, our problems of government and society would be attacked in a more logical and less emotional manner. Selfishness and dishonesty will probably always be with us, but a true scientist can not accept what he knows to be false and wrong; otherwise he is not a scientist. Furthermore, he studies the problems in an impersonal way. Enough men of this type would

bring order out of a chaotic world. Some of our colleges are introducing courses in social science to accomplish such results. For example, the Carnegie Institute of Technology has established the Maurice Falk Professorship of Social Relations.

If our colleges really have become as rigid as some persons allege, let us consider in detail a few of their criticisms. The first is that the college is going blindly ahead and does not know what its objective is. In other words, have we an objective, and what are we trying to do in education?

Of course, it goes without saying that we are trying to educate our students; but the word "educate" has such a wide dictionary definition that it means different things to different people. Perhaps most of us would agree that we are primarily trying to develop the student. A general conception of the process of education might be somewhat as follows: The student comes to college with an unformed mind, lacking in logical opinions, unsure of his knowledge, with his values of life and things in general uncertain; and after four years of study and training he has acquired "poise," developed his opinions, corrected his values of life and molded his character. In other words, he has learned how to study and how to think and reason.

Perhaps most educators would accept in a general way some such statement as a definition of the aim and meaning of education, and so perhaps this answers the question of what the colleges are trying to do; at least, so far as their fundamental objective is concerned. But although we may know what we want to do, how to do it is the real question; and here it is that opinions and ideas differ greatly. On the one hand, some believe that the kind and type of subject taught to the student makes no difference whatsoever; on the other hand, some want nothing but scientific subjects given; while others would replace these with the

so-called cultural studies. And so it goes, with all sorts of opinions, even to the advocate of physical education who believes that it should have the most prominent place.

A second criticism made against the college is that it does not make useful men. Of course, such a generalization would be impossible to prove. Just what usefulness is, and whether college men succeed better in life than those without a college education, would involve a definition of "success." Counts of the number of college men listed in "Who's Who" and lists of college men receiving high salaries may be illuminating, but not conclusive proof. There is an impression among many people that a college education may make a happier man, but spoils him as a money maker and a successful business man. Without spending time over such a controversial statement, consider the following experience of a dean in one of our large engineering colleges.

This dean was sitting in his office one day when in came a man who had graduated from this institution some two or three years before. The graduate said: "Dean, why don't you put more technical studies in your engineering courses? What a man needs when he gets out in the world is a knowledge of things that can be turned to use and that will make him more valuable to his employer."

The next day a graduate who was considerably older and had been graduated some fifteen years came into the dean's office. He said: "Dean, I can't understand why it is that you put so many technical subjects into your courses. What a man needs is not so much technical matter, which he can not help picking up in his practice, but broader subjects which he can not easily get outside of college."

The third day a man who had been graduated some thirty-five or forty years came in. He said: "Dean, I tell you what

you ought to put into your courses; and that is philosophy."

In discussing what kind of studies and training should be given (and this is particularly true of the technical school), the question always arises: Why can not the student's mind be developed by studying useful subjects? Or, to state it in another way: How much of education should be devoted to training the student to make a living? The economic side must of necessity be of interest both to the student and to industry. Ask the ordinary engineering student why he chose to go to a technical instead of to an academic college, and the majority of answers will be, because he thinks that the technical school will fit him for a job after graduation. And even if the student is not thinking actually in dollars and cents, he still has an underlying feeling that it gives him a profession or vocation, which really is an economic reason. A great many young students have somehow gotten the idea that education is a matter of acquiring a great mass of facts, and that is all that is necessary to assure making their fortunes after graduation. Thus the economic problem is one which young men are thinking about, and the educator can not safely neglect it.

If the above-mentioned dean were asked if he considered cultural studies necessary in an engineering course, he would undoubtedly say that he did. He might give as his reasons that men who study in one field only become highly specialized and narrow, and that they lack breadth of knowledge and do not appreciate the bearing or influence of other fields on their own. Furthermore, such subjects as literature, history and the like round out the student and help greatly in developing his character, show him how to get more out of life, and interest him in human affairs and make him a better citizen generally.

This is the type of argument usually advanced; but the dean might have taken

a very different line. He might have argued from a very practical standpoint. Take, for instance, a graduate who has a good technical knowledge, but knows little of literature and who has a poor command of English. This is not by any means the chance student, for any one familiar with our great technical colleges knows that such a man is quite a common product. As some pessimist has said, "He can not write, he can not read; all he knows is gears and wheels." It is not as bad as this, but this type of graduate we all recognize. If such a man is to remain a mechanic and work by himself over inanimate things, he may keep along the even tenor of his way; but suppose he is taken into an office and asked to write the specifications for a machine. He can not do it; not because he lacks the technical knowledge, but because he can not express his ideas in English. In other words, it does not make any difference what his technical knowledge is, to be of value to his employer he must also know English.

Suppose again this man is asked to sell a machine. As we all know, there is something besides technical knowledge that makes a salesman. Broadly, there are two types. One type of salesman comes to his customer and says: "Here are the specifications for the engine you need. I do not know much about them, but my firm turns out the very best engine made. Come along and have lunch with me." The other type may not have address enough to ask a customer to lunch with him, and would not know what to do if he did; but he may know the details of the engine perfectly.

Now which of these men will sell the engine? It may depend somewhat on the type of buyer, but generally, the man who can talk, in spite of his technical ignorance. We see this everywhere, the man who knows the most is not the man who sells the most. As a soap manufacturer says: "Any fool can make soap, but it takes a genius to sell it."

Take, for example, a prospective customer of the nervous type who has a long, thin face. Such a man is quick in his movements and actions; and not only is he quick physically, but he is a quick thinker as well. This man will not listen to the details of a long specification. He wants to jump at his conclusions, and if you suggest things to him, letting him give you the answer, he is often flattered. Whereas the man with the large, square face, more of the lymphatic type, is generally a slow thinker and will follow your explanation through detail after detail. It would be useless to explain a blueprint to the first man, while the second will be interested. Between these two extremes there is every combination.

One of the most successful technical salesmen this country has produced started out as an office boy in an eastern railroad office. He never had any scientific training, and what little technical knowledge he possessed he picked up as he went along. But he had that wonderful intuitive knowledge of human nature that is so rare. When he talked with a customer, he unconsciously felt the type of man he was talking to, and somehow fitted himself into the man's mood. Every one liked him. He had that intangible thing we call "personality."

Do not misunderstand nor think that this is written in disparagement of technical knowledge. Not at all, for the ideal salesman must combine technical knowledge with a broad human knowledge. Superintendents and operating men often have a tendency to look down on the technical salesman; but after all, is not the president or high official of a manufacturing concern a good salesman? One of the reasons why he is where he is, is that he can "put over" his ideas. Whatever truth there is in the old saying, "Salesmen are born, and not made," it is certain that the college can help a very great deal in developing what talent the student has.

The above is merely a strong argument

for introducing more cultural subjects into our engineering colleges, and also for broadening the student as much as possible. Many students get as much perhaps by contacts with other students and with teachers as they do from studies; and certain college activities also help to broaden the student's horizon. A truer estimate of a student can generally be obtained from his fellow students than from the faculty, because the student body in their judgment takes into account all those qualities which go to make up his character and personality, while the faculty, knowing his scholastic attainments better than his other qualities, judge him in a narrower way.

So breadth of knowledge is necessary in the engineer, as well as technical information. Not long ago the head of one of our large industrial corporations made the following statement: "We can get plenty of men who are technically competent, who are careful and thorough in their investigations, whose conclusions are sound, but who can not make a favorable impression before a board of directors. We can get plenty of lawyers who, after being properly coached by our engineers, can glibly and even convincingly talk to the same board of directors, until some question is asked which has not been covered in the process of coaching; then they too flounder about. If we could secure a man who possessed the conscientious thoroughness and accuracy of the engineer, and also the facility of expression and persuasiveness of the lawyer, we could afford to pay him any salary he might ask."

Obviously, therefore, a college must do something beside teach specialization. A compromise must be made to meet the needs of various students. Referring again to the above three men who interviewed the dean, each of these men had his needs. The youngest man had to make a living, the older man, in a responsible position, was not interested in details but in breadth of view; while the

last man had perhaps become more interested in the broad principles of life. It would seem, then, that there is a cycle that most graduates go through in after life. And this seems quite a reasonable conclusion, inasmuch as almost everything we know of goes in a cycle, from a solar system down to human life; and as education is part and parcel of our life history, as a man gets on in life his knowledge and outlook change. It is a commonplace that men of the same age naturally find more in common to talk about. Old men do not as a rule associate with young men.

One other criticism which has been made against the college is the lack of thoroughness of teaching; and this is perhaps the most valid of all the criticisms and the hardest to answer. It may be that many of our educational institutions try to cover too much ground. Specialization and the constantly growing body of knowledge have placed the college in a very difficult position. This is especially true of engineering colleges, for they feel that a certain amount of ground must be covered by the student and the tendency is to jam him over it. We sometimes lose sight of the development and training of the student's mind, by thinking that the necessary thing is to fill him up with knowledge. To push a student over ground but half understood surely is not properly education at all. In addition, it teaches him bad and careless habits of thought and produces a mind improperly trained. One subject which the student has really grasped is worth more to him than the hazy smattering of a great many. Is not a scholar one who knows what he does know? It would be a great deal better to cover less ground, and make sure that what is gone over is really understood. Suppose we do not teach as many subjects. No college can turn out a finished man in any line. The graduate will find, no matter what he takes up, that further study is necessary. If a cer-

tain subject has not been covered in his college course, he can, if he has the proper fundamental knowledge, get it for himself. No college can cover all human knowledge, and education does not stop at graduation.

Of course, the personality and experience of the teacher count; but after all, no matter how good the teacher, he must be given the necessary time to present his subject and the student the necessary time to properly digest it. Every teacher knows that there are certain students who get along with enough coaching to pass routine examinations, but who really have no true grasp of the subject.

Some day the college course of four years may be lengthened; and there are a large number of students to-day who take postgraduate courses. Many students go first to an academic college, and then finish in a scientific or technical college. However, many valid objections can be raised against increasing the time spent in college; and it seems likely that we will retain the present four-year length for college education at least for the present. At any rate, the best way to improve our education would be to teach less, but teach thoroughly what we do teach.

Summarizing what has been said:

(1) College education is fundamentally a matter of student development, not of the amount of knowledge acquired. It is not the accumulation of facts, but a training in methods of thought. Facts can be acquired outside, but the function of the college is to teach how to reason and think. Most colleges do this at the present time; and therefore the criticism that the college has no objective is not a valid criticism.

(2) The idea held by many people, particularly young engineers, that cultural or liberalizing studies have no practical value, is entirely wrong. On the contrary, they have a very great practical value and help directly in making a living. Criticisms that our colleges do not turn out useful men are not well founded.

(3) It is better to teach a few subjects thoroughly, rather than to try to cover a certain amount of ground regardless of quality. Such methods make careless and inaccurate men. Criticisms of this kind do have a certain validity. Some of our colleges, particularly some of our technical schools, seem to believe that the student is not properly trained for his profession, unless a certain ground has been covered. Such criticisms are profitable and constructive.

BOOKS ON SCIENCE FOR LAYMEN

CIVILIZATION AGAINST CANCER¹

DR. LITTLE has undertaken a difficult task in assuming the burden of instructing the layman in modern aspects of cancer research and at the same time outlining for him the difficulties which arise in schemes for cancer control—difficulties which are not only financial but also human. In so doing he has produced a readable book and one rather brimming with optimism. In fact one gets the impression that we are very much "on our way" toward speedy control of this group of diseases—an attitude less shared by those who have to face the ever-increasing mortality figures from cancer. Still it is impossible for one who heads the American Society for the Control of Cancer to assume a pessimistic mood toward the problem to which he has dedicated himself.

The book arouses several reactions in the mind of the reviewer. How impossible it is for the individual to follow Dr. Little's advice to "Train yourself to overcome fear by disciplining your mind to face and consider the possibilities of cancer before they become actualities." The average human being just won't do this. His mind can not be trained to anticipate lethal disease, and a brain so conditioned is a psychiatric problem. Again, there are the rules for increasing one's chance of avoiding cancer. The first three rules pertaining to oral cleanliness and dental hygiene, removal of certain moles, and protection of the skin from excessive solar radiation, are sound and firmly attested by long experience. The remaining five, although usually stated as means of avoiding cancer, are, with the possible exception of the seventh, which pertains to gynecologic hygiene, wholly vague and unconvincing. Tight brassières are mentioned. In the old days it used to be the steel corset stay, but now that menace has been removed by stylists and yet we have the same incidence or possibly a higher incidence of mammary cancer. The rela-

¹ *Civilization against Cancer*. By C. C. Little. vi+750 pp. \$1.50. Farrar and Rinehart.

tion between gastric cancer and overeating is improbable. Did not primitive man gorge and do not less civilized peoples stuff when the occasion arises and otherwise fast? The feeding habits of English royalty in the days of the eighth Henry, as portrayed by Charles Laughton, seem to have been such that they all should have died of gastric cancer, and as for the effect of concentrated urine on development of bladder cancer one must remember that the dog is a source of experimental betanaphthylamin bladder cancer, and yet no animal according to common observation has less tendency to retain urine in the bladder than has man's best friend.

These musings of the reviewer only go to show how vague the causes of human cancer really are. When we come to experimental cancer, be the predominant factor heredity or be it a phenanthrene ring compound, we are on firm ground at least so far as present knowledge extends, and the contrast between that sort of knowledge and rank medical superstition is obvious from Dr. Little's book. Speaking of medical superstition, Dr. Little's illustration of the stuffiness of meetings of distinguished medical men is refreshing to the initiated.

A notable event in the annals of cancer took place with the presentation of Peyrilhe's essay before the Lyon Academy in the late eighteenth century—an essay written in response to the question, *Qu'est ce que le cancer?* Dr. Little's book answers it again for the layman and shows the progress made since that day, and above all how far we still must go before humanity can be satisfied. The humorous excursions of the reviewer do not detract from the value of the book.

FRED W. STEWART

FUNDAMENTALS OF THE PETROLEUM INDUSTRY¹

THE experience of the author, primarily in the production of petroleum,

¹ *Fundamentals of the Petroleum Industry*. By Dorsey Hager. Illustrated. xvii+445 pp. \$3.50. McGraw-Hill Book Company.

qualifies him for undertaking a comprehensive general treatise on the petroleum industry. Although the first three chapters, dealing with the place of petroleum in modern world economy, the history of the industry and the corporation organization of the industry as a business, are neither as well written nor as well organized as later chapters of the book, they contain a considerable amount of statistical data illustrating the growth and present importance of the industry. The 13 billion dollar investment in the industry in the United States and the estimate that the energy obtained from crude oil is more than ten times the energy obtained from water power in the country are among the data given as proof of the importance of petroleum.

Mr. Hager has arrived at a more optimistic point of view regarding the future supply of crude oil than most experts in this field, but his method of approach to the problem is interesting. He points out that exploration has been more extensive in the United States than in any other country and that the area of the United States is about one fourteenth that of foreign lands, excluding Greenland and other polar lands covered with ice sheets. He then applies this factor to the estimated future oil recovery of the United States to obtain a rough estimate of the future reserves to be discovered in the world as a whole. Two criticisms of this method of approach are immediately apparent. First, since the original oil reserves in most foreign fields have been only slightly depleted, a more correct base for the application of the area factor would be the ultimate recovery of the United States, composed of about 20 billion barrels of past production plus the estimated future production.

Second, a more fundamental criticism may be made of the use of total land areas as a basis of comparison. As is shown by the tabulation of proven reserves for the United States prepared by the American Petroleum Institute and included in

Mr. Hager's book, about 80 per cent. of the total is available in Texas, California and Oklahoma. As is well known to petroleum geologists, the great accumulation of oil in these states is due to the presence of basin areas in which great thicknesses of young and slightly altered marine sediments remain. There is no present basis for anticipating the discovery of important oil reserves except in areas having similarly favorable regional geologic conditions.

The sections of the book on the amount of oil recovered per acre and the acquisition of oil lands and royalties should serve to show a potential investor in properties of this sort that there is a wide range in their value and that investments should be made only after approval by competent experts. Although the business of producing oil and particularly of drilling and completing wells is given much greater emphasis and in much greater detail than is justified by its place in the industry as a whole, this lack of balance reflects the experience and point of view of the author and may conform to the relative interest of the average reader. These chapters are well organized and well written.

The chapters on transportation and storage would have been more useful if the accessibility of the major oil-consuming eastern industrial region to marine transportation and the advantage of cheap ocean transport for petroleum to fields near tidewater both in the United States and in foreign countries had been fully discussed.

The chapter on oil refining would have been improved by a few paragraphs pointing out the relationship between refining methods and crude oil requirements. Due to improvements in refining processes there is to-day less difference in the refining value of different types of crude oil than at any previous time. The author might well have discussed at more length the effect of changes in refining methods on the demand for crude oil.

Not only does cracking produce more gasoline per barrel of crude oil, as pointed out by the author, but improvement in the burning characteristics of the motor fuel produced has enabled motor manufacturers to design and build motors with higher compression. Such motors have higher efficiency and tend to reduce crude oil requirements.

In summary, although as indicated "Fundamentals of the Petroleum Industry" would be improved considerably by a different treatment of some of the subject-matter, it is mainly sound and well written. It merits reading by those interested in this important industry.

GAIL F. MOULTON

FROM MUSCLE TO STEAM¹

ONE has only to read this excellent book to realize what a transformation of the world has been brought about in 150 years and mostly within 75 years by steam and electricity. Although the author has written a straightforward account of the development of the steam engine from the time of the experiments with air pumps by von Guericke (1602-86) to the present time, fortunately he has done it with such clarity and with so many human touches that his story will be as interesting to the layman as to the scientist. No one can read that story without realizing that during the past two centuries the human race has passed through the most important period of its history. Nor will one doubt that in the perspective of some distant future the political struggles that have attracted, and now attract, the attention of the world have been of relatively trivial importance.

It is generally believed that James Watt, after noticing steam raising the cover of a tea kettle, was suddenly inspired (1765) with the conception of the steam engine and constructed one. That

¹ *A Short History of the Steam Engine*. By H. W. Dickinson. xvi + 255 pp., 78 figures + x plates. Cambridge University Press (Macmillan Company). \$3.50.

story is on a parity with the one that a falling apple led Newton to the discovery of the law of gravitation. As a matter of fact, approaches had been made to the principles that underlie the steam engine for nearly 100 years. Among those who were working on the problem Thomas Savery (1650-1715) and Elias Newcomen (1663-1729) stand first. Each produced and operated complete engines.

Both Savery and Newcomen made use of the pressure of the air instead of the pressure of steam to operate their engines. They first displaced the air in cylinders by steam and then condensed the steam. The great advance in principle introduced by Watt in 1765 was that he employed the pressure of steam against the pressure of air on the opposite side of the cylinder head, and later steam engines used both principles.

There is a wide-spread belief, due in part to recent governmental propaganda, that water power is not only much cheaper than steam power but a rival of it. In 1929, according to figures released by the World Power Conference, 79.1 per cent. of all mechanical energy generated in the world was produced by coal, 15.7 per cent. by petroleum and only 5.1 per cent. by water. The installed capacity of water power, however, was about 60 per cent. of that of steam, the low production of energy being due to the fact that generally water power is seasonal. In that fact lies its relatively high cost.

As interesting as the early history of the steam engine is, it is no more fascinating than the recent developments of high pressure boilers and steam turbines. Since all these phases of the evolution of the steam engine are thoroughly covered by the author, including quantitative results, the book gives a valuable survey for the engineer, as well as a thrilling story for the intelligent person who is interested in the forces that are molding our civilization.

F. R. M.



DR. ENRICO FERMI

THE PROGRESS OF SCIENCE

ENRICO FERMI—NOBEL PRIZE MAN IN PHYSICS FOR 1938

THE award of the 1938 Nobel prize for physics to an Italian physicist, Enrico Fermi, surprised no one, for he was as clearly marked for attention by the awarding academy as was, for example, his sole Italian predecessor, Guglielmo Marconi, when he received the award in 1910. The immediate basis of the award to Fermi was the discovery of atomic transmutations that can be brought about by the addition of neutrons to the nuclei of atoms, and the brilliant series of experimental researches on these transmutations and on the properties of neutrons which he, with his collaborators, accomplished at the University of Rome in the years 1934 to 1938. The production of many kinds of new radioactive atoms, the discovery of the effectiveness of slow or practically stationary neutrons in combining with surrounding atomic nuclei to form these new radioactive atoms, gave an enormous stimulus to research on the nature of the nuclei of atoms, the story of which can not be attempted here.

Fermi is 37 years of age. He was a Roman boy and attended the usual succession of schools in Rome. At the age of thirteen he developed a great interest in mathematics. Guided by an engineer friend he read and mastered more mathematics, even before he went at the age of seventeen to the Scuola Normale Superiore at Pisa on a scholarship, than he was required to learn in attaining the doctor's degree in theoretical physics. From boyhood he had also a lively interest in experimental physics. Few of the Nobel prize winners in physics have been men so thoroughly at home in both theoretical and experimental research.

After graduating from Pisa in 1922 he went to Göttingen to study, principally with Max Born, for seven months. It was the time just preceding the devel-

opment of wave mechanics and the uncertainty principle, when the quantum theory was being deeply studied and discussed. Heisenberg, who was to make such important contributions within the next two years, was a fellow student. A year at the University of Rome came next, then came a visit to Leyden, where, with Ehrenfest, Goudsmit, Kronig and others, Fermi matured and developed self-confidence. For the next two years Fermi had an appointment at the University of Florence, where he began his major contributions to theoretical physics by developing what is known as the "Fermi-Dirac statistics," which extends to the motions of the molecules of a gas the already known fact that in an atom no two electrons can exist in the same quantum state. This became of especial importance when applied to the electron gas in a metal.

In 1926 he went back to Rome as professor of theoretical physics, continuing at first mainly theoretical investigations such as his notable development of a theory of β -ray radioactivity, based upon the hypothesis of the existence of the *neutrino* or uncharged particle of mass very small compared to that of an electron.

From 1930 on he has visited this country often, usually to lecture at the University of Michigan Summer Session, though he has taught also in summers at Stanford and Columbia.

Very direct and clear in his thought and speech, sincere but not too serious, using few unnecessary words, he is recognized as an outstanding teacher. In experimental work also he achieves the direct and simple approach, and in his discoveries he exemplifies well the fact that only the clearest minds can for the

first time do the things that immediately thereafter are so simple and obvious for any one.

After his visit to Stockholm last December to lecture before the Swedish Academy and to receive the Nobel prize in physics, at the same time as the American writer Pearl Buck received the Nobel prize in literature, Fermi came directly to the United States to be professor of physics in Columbia University, where since January he has been engaged in active research on the splitting of ura-

nium atoms. In coming, in response to a long-standing invitation, to make his home in this country, Professor Fermi brought with him his wife, Laura, daughter of an admiral of the Italian Navy, and their two children, Nella and Giulio. Mrs. Fermi has followed closely her husband's work, and has herself, together with the wife of Fermi's Roman colleague Amaldi, written a popular book, "Alchimia del Tempo Nostro," on Fermi's discoveries.

GEORGE B. PEGRAM

DR. HUBBLE AND ALBERT SAUVEUR, FRANKLIN MEDALISTS

Two trail-blazers in science, one whose concern is with the infinite and the other with the infinitesimal, were recently honored by The Franklin Institute at its annual Medal Day exercises. Dr. Edwin P. Hubble, who is largely responsible for the exploration of a thousand million times as much space as was known a score of years ago, and Albert Sauveur, father of metallography in America and until his recent death the dean of this country's metallurgists—these two were named as recipients of the highest award the historic Franklin Institute can bestow. The presentation was made posthumously to Sauveur, his widow accepting the medal and certificate for her late husband.

Dr. Hubble, at the eyepiece of the world's largest telescope, made "investigations upon the nebulae, which surpass in extent, variety and success those of any other astronomer, past or present. . . . These investigations have extended the spatial frontiers of human knowledge in a greater proportion than any others in the history of science."¹

Born at Marshfield, Missouri, in 1889, Dr. Hubble majored in mathematics and astronomy at the University of Chicago, where in 1910 he won a Rhodes scholarship. For three years he studied at Oxford, receiving in 1913 his degree of

master of arts in jurisprudence. On his return to the United States he was admitted to the bar in Louisville, Kentucky, but the following year concluded that his strongest interests remained in scientific work. He resumed his study of astronomy, became an assistant at the Yerkes Observatory, and in 1917 received his doctor's degree.

At that time he enlisted in the infantry and served in France until 1919, when he was mustered out with the rank of major. He immediately joined the staff of the Mount Wilson Observatory, with which he is still connected.

In his studies of the galactic nebulae, Hubble has shown that these diffuse, irregular clouds shine by light reflected from neighboring stars. When the star is one of the "later" spectral type—cooler—the light, reflected from nebular dust clouds, produces a continuous spectrum, but when the stars are of an "earlier" type—with a surface temperature of more than 20,000°—their short-wave ultra-violet radiation excites the atoms in the nebulae, which then glows with a typical gaseous bright-line spectrum.

Working with the 100-inch telescope, Hubble has studied the spiral and other extra-galactic nebulae, and has shown that they are huge star clouds, compar-

¹ Dr. Henry Norris Russell, October 27, 1938.

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PRESIDENT PHILIP C. STAPLES PRESENTING FRANKLIN MEDAL TO DR. HUBBLE

able to our own Galaxy. He discovered in them Cepheid variables which have enabled him, by means of Shapley's period-luminosity relationship, to calculate the distances of the spirals. He has estimated the distances of the fainter and more remote clusters as 200 to 500 million light years.

A study of the red shift in the spectra of the nebulae confirmed the relation between distance and apparent velocity of recession. Hubble suggests that this shift may be due to some other cause than velocity of recession, and it is possible that a solution to this problem may come with the completion of the 200-inch telescope.

Sauveur, at the eyepiece of his microscope, began at an early age to study the structure of iron and steel, pointing the way for modern routine testing and research in industrial metals. He "taught the users of steel to use a microscope—something that users didn't know. . . . He found all kinds of things in the steel

that oughtn't to be there—like looking at a drop of water under a biological microscope. . . . He put metallography on the map when he founded and edited *The Metallographist* in 1899, afterwards the *Iron and Steel Magazine*."² He is generally regarded as having been the father of the science of metallography in America, and among metallurgists was affectionately known as "the Dean."

He was born at Louvain, Belgium, in 1863, and came to this country after completing his preliminary education in the School of Mines in Liège, and received his bachelor of science degree in mining and metallurgy from the Massachusetts Institute of Technology in 1889.

His first position was with the Pennsylvania Steel Company, where nobody seemed to know what should be done with a metallurgist, so he was assigned to a place in the chemistry laboratory. He

² William Campbell, *Mining and Metallurgy*, August, 1935.



ALBERT SAUVEUR

was left pretty much to his own devices, and spent the greater part of two years in studying the metallurgy of iron and steel. In 1891 he went to the South Chicago plant of the Illinois Steel Company. Here was found an old microscope, and a barrel was made to serve as a laboratory table while waiting for other equipment to be procured. In this manner was begun the work which was destined to play a major rôle in the manufacture and heat treatment of steel. From the time that Sauveur began his studies, the importance of this type of investigation has continually increased, and metallurgy, as

a modern science, owes much to this new avenue of study.

Photomicrographs of polished metals became a standard process of investigation. As early as 1893 he presented some of his findings on the relation between chemical composition and heat treatment before the Chicago meeting of the American Institute of Mining Engineers.

An international milestone in metallurgy was his 1896 paper on "Microstructure of Steel and Current Theories of Hardening." This contribution aroused tremendous discussion in this country and in Europe.

In 1899 he went to Harvard University as instructor and was assistant professor in metallurgy and metallography from 1900 to 1905. He was lecturer at the Massachusetts Institute of Technology until 1903. He became a professor at Harvard in 1906 and held that post until he retired from active teaching in 1935. His texts and scientific writings have been regarded as classical works in his field. Honorary degrees and awards were showered on him by universities and learned societies here and abroad. During the war he served in France as an aeronautical metallurgist, connected with A.E.F. He was United States delegate to the Pan-American Scientific Congress held in Lima, Peru.

The Franklin Institute's decision to honor him was made shortly before his death in January, 1939, and the medal and accompanying certificate were therefore presented to his widow.

A. S.

A HOSPITAL GROWS UP—MEMORIAL HOSPITAL IN 1939

THE Memorial Hospital for the Treatment of Cancer and Allied Diseases, of New York City, had its formal opening at its new site on June 14. The new home occupies the block at East 67th and 68th Streets between First and York Avenues, directly across from the Rockefeller In-

stitute for Medical Research and the Cornell Medical College and New York Hospital. Memorial Hospital's affiliation with Cornell Medical College, of many years' standing, is now more direct since moving into the district of the Cornell Medical Center.

The block on which the hospital is built was personally acquired over a period of years by Mr. John D. Rockefeller, Jr., for this purpose, at an approximate cost of \$2,500,000. The General Education Board gave \$3,000,000, and Mr. Edward Harkness gave \$500,000 for the building program. An additional \$300,000 was spent on new, special equipment; so that the total cost of the new Memorial Hospital, together with its large supply of radium previously purchased, stands at about \$8,000,000. This, according to a statement made by Dr. Ewing many years ago, approaches the amount of money which the ideal, properly equipped cancer institute should cost.

Due to the able leadership of Dr. James Ewing, for the past twenty-five years its director, Memorial Hospital has taken on the rôle of a leader of thought in the international field of cancer. This reputation has come as a result of its cancer researches in the laboratories of biology, physics and chemistry; as well as the development of greater refinements in cancer diagnosis and technique of treatment. To-day it stands as a cancer institute of national significance.

The program of the hospital opening consisted of a private dinner, on June 13, to Mr. John D. Rockefeller, Jr., held in the nurses' dining hall. Seventy intimate friends of Mr. Rockefeller and of the hospital attended. The speakers were President Day, of Cornell University; Mr. Walter Douglas, chairman of the board of trustees of the hospital; Dr. James Ewing, its director; the Honorable Jacob Gould Schurman, president of Cornell at the time of the affiliation of Cornell and Memorial, and Mr. John D. Rockefeller, Jr.

On the morning of June 14, a scientific meeting was held in the large, handsomely decorated auditorium of the new hospital. At this meeting, Dr. Burton T. Simpson, director of the New York State Institute for the Study of Malig-

nant Diseases, at Buffalo, discussed "The Pioneer Cancer Institutes in America." He spoke of the significant contributions made by the Memorial Hospital staff, and compared the work of the various early cancer hospitals. Dr. Frank E. Adair, attending surgeon and executive officer of Memorial Hospital, in "The Position of a Cancer Institute in Relation to the General Medical Profession," outlined the three major lines of attack on the cancer front as they are being carried forward by the American Society for the Control of Cancer, the American College of Surgeons (in their 272 cancer clinics) and the special cancer institute, such as is represented by Memorial Hospital.

Dr. Lloyd F. Craver, attending physician and chairman of the fellowship committee of Memorial Hospital, spoke on "Graduate Education in Memorial Hospital," showing that there is a great demand for men specially trained as experts in diagnosis and treatment of cancer. Dr. James Ewing, director of Memorial Hospital, spoke on "Planning the Memorial Hospital Building," in which he contrasted the construction problems of an ordinary general hospital with the special problems which surround the maintenance and servicing of such an electrical and radium plant as the new Memorial. William D. Coolidge, Ph.D., director of research laboratories of the General Electric Company, spoke on "The Contributions of the Physical Sciences to Cancer Therapy," outlining the development of the older therapy equipment with the new units installed in the new Memorial.

In the afternoon, the hospital was declared formally open for service by the president of the board of trustees, Mr. Harry Pelham Robbins. At this service, other speakers were Dr. Ludvig Hektoen, director of the National Cancer Council of the United States Public Health Service, Dr. Sigismund S. Goldwater, commissioner of hospitals of the City of New



THE NEW MEMORIAL HOSPITAL

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York, and the Honorable Jacob Gould Schurman.

The Memorial Hospital has certain new features of interest. The x-ray therapy department is probably the largest in the world, extending completely across the south side of the hospital along 67th Street. It contains a million-volt "pocket edition" type for deeply situated cancers; five 250 K.V. therapy machines with easily adjusted portal openings, a new invention of Dr. Gioacchino Failla, the physicist; four 200 K.V. therapy machines; and two low voltage

therapy machines. Apart from the large amount of x-ray diagnostic and therapy equipment, the hospital has nearly ten grams of radium. It was this large radium supply which helped build up the reputation of the hospital many years ago. The second floor has huge space for the laboratories of physiology, biology, chemistry, physics and biophysics. It is anticipated that with the improved housing of the laboratories renewed vigor will be thrown into the work of the fundamental researches of cancer.

FRANK E. ADAIR, M.D.

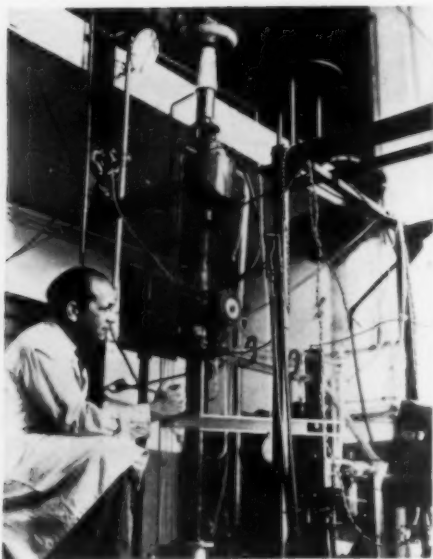
THE ELECTRON MICROSCOPE

UNDER substantially the above title Dr. V. K. Zworykin presented a paper at the Virginia meeting of the American Association for the Advancement of Science which was of great interest from both the theoretical and the practical points of view. Moreover, it was demonstrated in the exhibits of the Radio Corporation of America in the annual scientific exhibition. Although the subject of the electron microscope is relatively new, contributions have been made to it by a considerable number of scientists.

Thousands of persons, amazed at the revelations of microscopes, have wondered why opticians do not continually make them more and more powerful, just as manufacturers produce speedier and speedier automobiles and better and better radio receiving sets. They read from time to time of larger and larger telescopes that have power to penetrate farther and farther into the celestial spaces, even to distances that light can traverse only in hundreds of millions of years. Then why not, they ask, make microscopes that will enable scientists to explore correspondingly downward toward the infinitesimally small? They hear of micro-organisms, some of them causing diseases of animals and plants,

that are beyond the reach of microscopes. They learn of organic molecules which are composed of thousands of atoms, yet are also far beyond the range of microscopes. They ask why microscopes can not be placed one behind the other, each magnifying the image formed by its predecessor. An occasional report of the invention of some new kind of microscope encourages them to believe that finally opticians have stumbled on what should have been obvious all the time.

In spite of the never-dying hopes of the uninformed that a super-microscope will be invented, scientists know that there are limitations to the power of microscopes if they depend upon light for their operation. For clarity a few words about the meaning of "power" are necessary. What the word normally means in this connection is "resolving power," which is, for example, the ability to show equally spaced parallel lines, like those in an engraving, as separate lines. Now light is made up of waves whose lengths range from about a forty thousandth of an inch, in the red, to an eighty thousandth of an inch, in the far violet. There are infra-red rays having longer waves than the red and ultra-violet rays having shorter waves than the violet.



THE ELECTRON MICROSCOPE
OF L. MARTON IN BRUSSELS. THE INSTRUMENT
MEASURES TEN FEET FROM THE COLD CATHODE
DISCHARGE TUBE AT THE TOP TO THE PLATE
CHAMBER NEAR THE FLOOR.

The lengths of these waves are the limiting factor in the resolving power of an optical instrument, however it may be designed and however perfectly it may be made.

As a consequence of the wave property of light, an optical image of a point source of light is a little circle surrounded by a series of concentric rings of rapidly decreasing intensity. Similarly, an optical image of a line, even infinitely fine, is a narrow streak bordered on each side by parallel streaks of rapidly diminishing intensity. It is easy to see that, if several parallel lines, however fine they may be, are so close to each other that the streaks of their optical images merge, they are not resolved into separate lines and that no further magnification will help.

The rule is that the resolving power of a perfect microscope is about one half a wave-length. Therefore in red light parallel lines can not be separated if they

are closer together than about one eighty thousandth of an inch; with violet light the limits are about half as great. Then why not use the shorter wave-lengths of ultra-violet radiation, of course by photographing? It has been done, but the increase in resolving power has been only about twofold. Much shorter wave-lengths can not be used, because the glass in lenses is not transparent to them.

Since x-rays pass through glass and even substances opaque to light, why not use them, for their wave-length is of the order of a thousandth that of light, and consequently the resolving power with them would be a thousand times as great? The answer is that though they are analogous to light no suitable means for refracting them to form images has been found. As scientists began to despair of the possibility of a supermicroscope a new and entirely different method achieves ap-

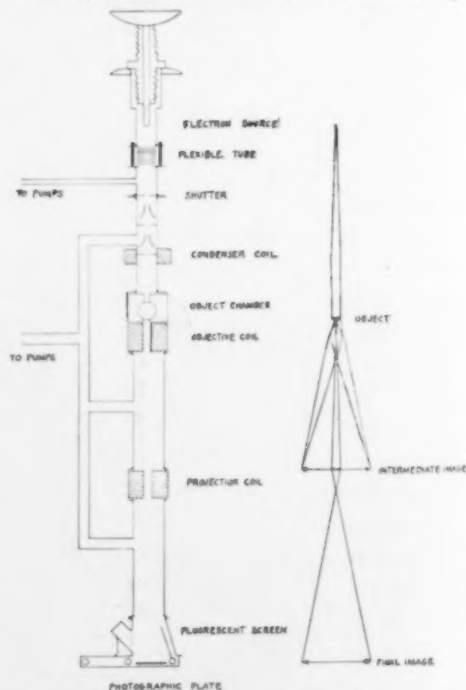


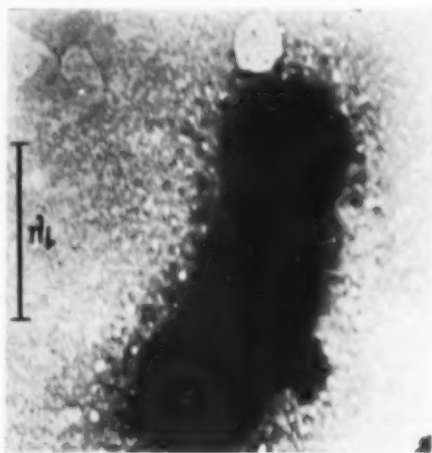
DIAGRAM OF ELECTRON MICROSCOPE
SHOWING PATHS OF THE ELECTRONS FORMING THE
ENLARGED ELECTRON IMAGE.

proximately equivalent results. Instead of light or anything having the essential properties of light, the new method uses electrons which are negatively charged particles. Yet, as the French physicist de Broglie found in 1924, there is associated with each electron a sort of wave motion whose wave-lengths are related to its velocity. Electrons are not refracted as light waves are, but since they carry electric charges they may be deflected by electric currents and magnetic fields.

Now we have in rough outline the underlying principles of the new electron microscope. Instead of using electromagnetic (light) waves that are refracted by suitable media (lenses) which change their velocities, the new instrument employs streams of electrons that are deflected at pleasure and brought to a focus by suitable electric and magnetic fields. This statement, however, is an over-simplification. Refractive media, such as glass, have essentially constant refractive properties throughout. The effects of electric and magnetic fields, on the other hand, vary from point to point, often by large amounts. Consequently, the relatively simple theory of lens systems can not be employed in the control of the paths of electrons by electric and magnetic fields. In addition, there are certain physical laws which express limitations on the way in which the effects of both electric and magnetic fields may vary. When all these properties are taken into consideration, it is found that what corresponds to spherical aberration (defects in optical images due to the use of spherical surfaces) can not be completely avoided in electron instruments. And since the initial velocities of electrons vary, the defects corresponding to chromatic aberration in ordinary lens systems can not be avoided in electron instruments.

On the other hand, electron optics is much more flexible than light optics. A lens surface once formed is permanent;

electric currents and magnetic fields may be varied almost at will. Another important point is that the velocities, and therefore the energies and the effects of electrons, may be increased by electric fields. In the case of light optics, however, no increase of light energy in the optical system is possible; on the contrary, much light energy is lost by reflection from surfaces and by absorption. The energy of the electrons may finally

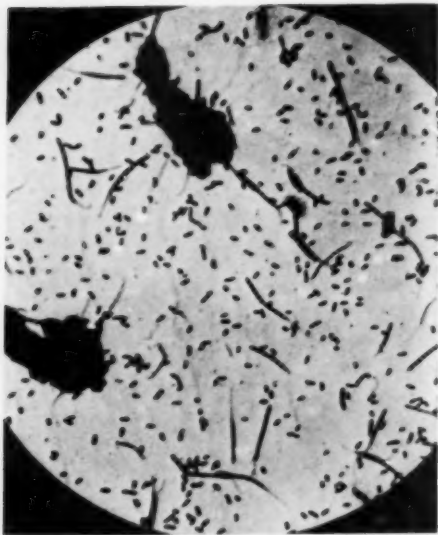


A SINGLE BACTERIUM

Staphylococcus aureus (DARK MASS IN CENTER)
—ELECTRON-OPTICALLY MAGNIFIED 20,400 DIAMETERS; MAGNIFICATION IN PICTURE ABOUT 150,000 DIAMETERS. B. V. BORRIES AND E. RUSKA, WHO TOOK THIS PHOTOGRAPH, SUGGEST THAT THE FINE STRUCTURE SURROUNDING THIS PUS-FORMING BACTERIUM IS DUE TO PRODUCTS OF ITS METABOLISM.

be transformed, though with some losses, into light, by a fluorescent screen, and therefore the final image is in light, as in the ordinary microscope.

Fluorescent screens and the fundamentals of the electron microscope are used in the television developments which have been carried out by Dr. Zworykin and his associates. In television the image of the scene that is to be transmitted is dissected into lines (scanned) which must be repeated a large number of times per second. These same principles have re-



A CULTURE OF BACTERIA
Chromobacterium prodigiosum, MAGNIFIED ELECTRON-OPTICALLY 750 TIMES (L. MARTON).

cently been applied in the development of an electron microscope for the purpose of reducing the slight defects which correspond to chromatic aberration in light microscopes.

In attempting to make the principles of these promising developments understandable by those who are not expert in the field, the problems have been somewhat over-simplified and numerous prac-

tical difficulties have been ignored. The first applications of these new methods have been to investigating the structures of metals and alloys, partly because the obtaining of electrons from such sources is easy and partly because it has been desired to follow the changes in structure to high temperatures. The difficulties in applications in biology are formidable, for everything has to be done in a high vacuum. Yet as serious as these and other difficulties are, they have already been largely overcome, particularly through the efforts of Dr. L. Marton, and photographs of micro-organisms with magnifications far beyond the possibilities with light microscopes have already been obtained. Dr. Zworykin closed his discussion of the results so far accomplished by various workers, European and American, in this field with these words: "We feel that the present developments in electron optics justify the belief that the day is not far off when electrons will play an essential rôle in biological science, as well as in the study of metals and related disciplines, aiding man to advance further his understanding and his mastery over his environment." Science is reaching as eagerly downward toward infinitesimals as outward toward the infinite.

F. R. MOULTON

SCIENCE DISCOVERS BASIS FOR MAINTAINING MARINE FISHERY RESOURCES

A THEORY which not only explains an important cause of fluctuations in the abundance of fish in the sea but which may also provide the basis for managing high seas fisheries for the benefit of man has recently been advanced by William C. Herrington, in charge of the North Atlantic research staff of the U. S. Bureau of Fisheries.

According to Mr. Herrington, too many haddock on the fishing banks off the New England coast are just as undesirable as too few from the standpoint

of maintaining maximum production of the fisheries over a long period of years. This seemingly paradoxical statement is based on the discovery of a certain optimum level of abundance for the fishery—the level at which the largest numbers of young haddock are produced and survive. If the total stock falls below or rises above this level, the fishery fails to receive its normal additions of young in succeeding years.

The importance of this generalization lies in the fact that it provides, for the

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first time in the history of marine fishery research either in Europe or America, a basis for a rational exploitation of a marine fishery, an undertaking which has ordinarily been regarded as beyond the control of man.

The plan for the management of the haddock fishery rests on a mass of evidence accumulated by Mr. Herrington and his staff during an eight-year investigation into the causes of the recent decrease in the availability of haddock to the commercial fishing fleet. This decline amounted to approximately 75 per cent. between 1927 and 1931 on Georges Bank and South Channel, the principal New England fishing grounds, and threatened the prosperity of the haddock fishery, which during the 20's had expanded to first place in poundage and value among all New England fisheries, relegating the "sacred cod" of almost legendary fame to second place. This decline, it was

found, was partly the result of the intensive fishery that had developed since 1926. Primarily, however, it was due to the fact that relatively few young haddock were produced from the spawning seasons in 1926, 1927 and 1928, so that in later years there were practically no young haddock coming to commercial size to replace their elders which had been taken by the fishery.

How to explain the failure of the spawning seasons of 1926-28 was the principal problem, for in these years spawning adults were abundant. Similar failures of young to survive from one or a series of spawning seasons have been noticed in some of the great marine fisheries of Europe.

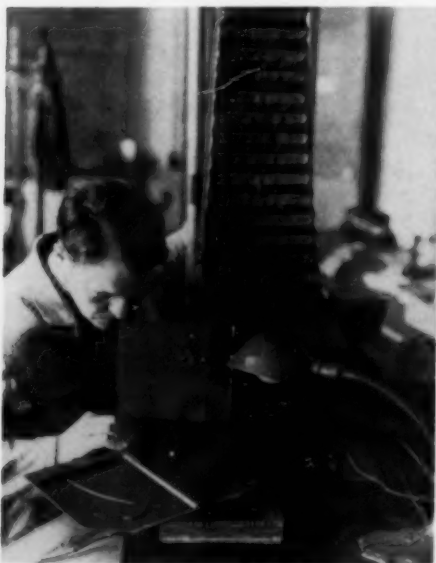
By comparing the average number of three-year-old haddock caught per day by the fishing fleet with the abundance of adults three years earlier, Mr. Herrington demonstrated the surprising fact



BIOLOGISTS ABOARD TRAWLERS TAKE A CENSUS OF HADDOCK POPULATION BY MEASURING THE FISH IN THE CATCH THEY DETERMINE THE RELATIVE NUMBERS OF YOUNG AND OLD FISH MAKING UP THE POPULATION. SUCH A RECORD OVER A PERIOD OF YEARS INDICATES WHETHER OR NOT A FISHERY IS BEING DEPLETED.

that survival of young was at its lowest point in years when large fish were extremely numerous. In such years the adult haddock were found to spread out over the nursery grounds—areas in which young haddock are ordinarily concentrated—and reduce the numbers of young, presumably by competition for food or directly through cannibalism. On the other hand, when the adults were greatly reduced through overfishing or from other causes, there were insufficient spawners and few young were produced. Tipping the scales of haddock abundance either way, therefore, reduces the stock available for the commercial fishery.

In addition to furnishing a clue to the recent decline, Mr. Herrington indicates a remedy: protection of the young fish during the early years of life during which growth rate is greater than natural mortality rate, and maintenance of



MICROPROJECTOR AND CALCULATOR
IN HANDLING SCALES, CELLULOID STRIPS ON WHICH THE SCALES ARE MOUNTED ARE RUN THROUGH A MACHINE WHICH PROJECTS AN ENLARGED IMAGE OF THE SCALE. A FEW MOVEMENTS OF A LEVER ARM AND SLIDER SHOW THE AGE OF THE FISH FROM WHICH THE SCALE CAME AND THE SIZE OF THE FISH AT EACH YEAR OF ITS AGE.



SCALE FROM A 3-YEAR-OLD HADDOCK
ENLARGED ABOUT 25 TIMES. WITH HADDOCK, COD AND SOME OTHER FISH, AGE AND GROWTH RATIO CAN BE DETERMINED FROM THE SCALES, WHICH WHEN EXAMINED UNDER A MICROSCOPE SHOW CONCENTRIC RIDGES SIMILAR TO THE RINGS ON A CROSS-SECTION OF A TREE. THE SPACING OF THE RINGS INDICATES THE AGE OF THE FISH.

the spawning stock near the indicated abundance level by regulation of the intensity of commercial fishing. Through earlier experiment, Mr. Herrington has already devised means of protecting baby haddock from capture in the commercial fishing trawls by developing nets with mesh size adjusted to prevent the taking of any considerable proportion of fish below a given size. As soon as analysis of the assembled data has been completed, the Bureau of Fisheries expects to offer definite recommendations to the commercial industry for the management of the haddock fishery.

R. C.

DOWN INTO THE EARTH

WHEN the Continental Oil Company, a short time ago, reached a depth of 15,004 feet in drilling for oil in California, it had penetrated the skin of the earth more than 2,000 feet deeper than any earlier drill hole. Mining shafts fall far short of these great depths, the deepest one, that of the Robinson Deep gold mine in South Africa, having reached only about 9,000 feet. Soundings have been made in the ocean to depths greater than 25,000 feet, but the water at the bottom differs only slightly from that at the surface. Mt. Everest has been ascended within approximately 1,000 feet of its summit, 29,002 feet above sea level.

The difficulties of drilling to depths greater than 10,000 feet are formidable. Cores of rock are cut out by a rotating drill pipe equipped with a bit at its lower end, after which protecting casings are inserted. In the first 500 feet of the record well the diameter of the casing was 16½ inches, in the next 5,500 feet it was

10½ inches, and in the remainder it was seven inches. The total weight of the casings was 225 tons.

At the bottom of this deep well the rock pressure, due to the weight of the rock above, is about 15,000 pounds per square inch, and the temperature is 270° F., or nearly 60° above the boiling point of water at sea level atmospheric pressure. It is evident that if there were no other difficulties, the high temperature alone would prevent the sinking of a shaft to such a great depth.

All the rocks in the 15,004 feet penetrated in drilling this deepest well are sedimentary and of modern origin, geologically speaking. The lowest and oldest strata reached are of Miocene Age, dating back only 15 or 20 million years, when the region was beneath a shallow ocean and ancient rivers carried sediments into it and dropped them on its floor. Among these sediments were organic materials which time and pressure and temperature



CALIFORNIA OIL WELL DRILL

and chemical changes gradually transformed into oil which was found in large quantities at a depth of 13,100 feet, the deepest oil-producing strata in the world. There are other wells more than 13,000 feet deep in Louisiana and western Texas, some of which produce petroleum.

As deep as the California well is, it is only one seventh of one per cent. of the distance from the surface to the center of the earth. Therefore, by direct examination only the thinnest skin of the earth is known. But by somewhat indirect and almost as certain methods a great deal is known about the interior of the earth even to its center. For example, it has been found from the gravitational effects

of the earth that its average density is 5.5 times that of water, or about midway between the density of surface rocks and that of steel. The earth-tide experiments of Michelson, in 1912 and 1917, proved that the earth is rigid rather than viscous as had previously been supposed. Now investigations of the properties of the seismic waves that pass around and through the earth are leading to definite conclusions about the general structure of its interior, including its several zones and the properties of the materials of which they are composed. This information is of course important in checking theories of the earth's origin and early history.

F. R. M.

AMERICA INHABITED FOR TWENTY-FIVE THOUSAND YEARS

IN a small area in northeastern Colorado, several thousand miles from the Aleutian Islands and Bering Straits, across which anthropologists think man first migrated from Asia to the Western Hemisphere, there are numerous stone weapons and implements left by human beings who lived approximately 25,000 years ago. These artifacts, left by what is known as Folsom man, are of a general type that have been found over a considerable part of North America.

The antiquity of these finds of stone weapons characteristic of Folsom man, and of the bones of long extinct animals associated with them, was determined by Drs. Kirk Bryan and Louis L. Ray, of Harvard University, from painstaking geological observations and an extraordinarily interesting chain of reasoning. The artifacts found in northeastern Colorado, in what is known as the Lindenmeier site, were buried on a gentle slope by glacial debris which Drs. Bryan and Ray determined by correlations with other deposits as being of the third Wisconsin glacial substage, and reported to the Milwaukee meeting of the American Association for the Advancement of Science. This period has been correlated

by its characteristic year-by-year fluctuations with glaciation in northern Europe, the age of which Antevs has established by counting the yearly deposits from glaciers at favorable locations. In this way the history of man in the United States, in which there was no pre-Columbian written history, is being sketched out for 250 centuries.

As yet not a great deal is known of Folsom man, though it may be inferred from the fact that he made highly specialized stone weapons and implements, which have been found in thirty states, that his was a virile race. The numerous chipped stone articles he left in the Lindenmeier area prove that he had camp sites and villages, and the ashes in these places are clear evidence that he knew how to start fires and use them for warmth and cooking. The broken bones of long extinct camels and bisons and other animals which he left among the ashes of his camps are proof of his prowess as a hunter. But like the animals he may have exterminated, he has been gathered to his fathers and it is not known whether he has descendants now living.

F. R. M.